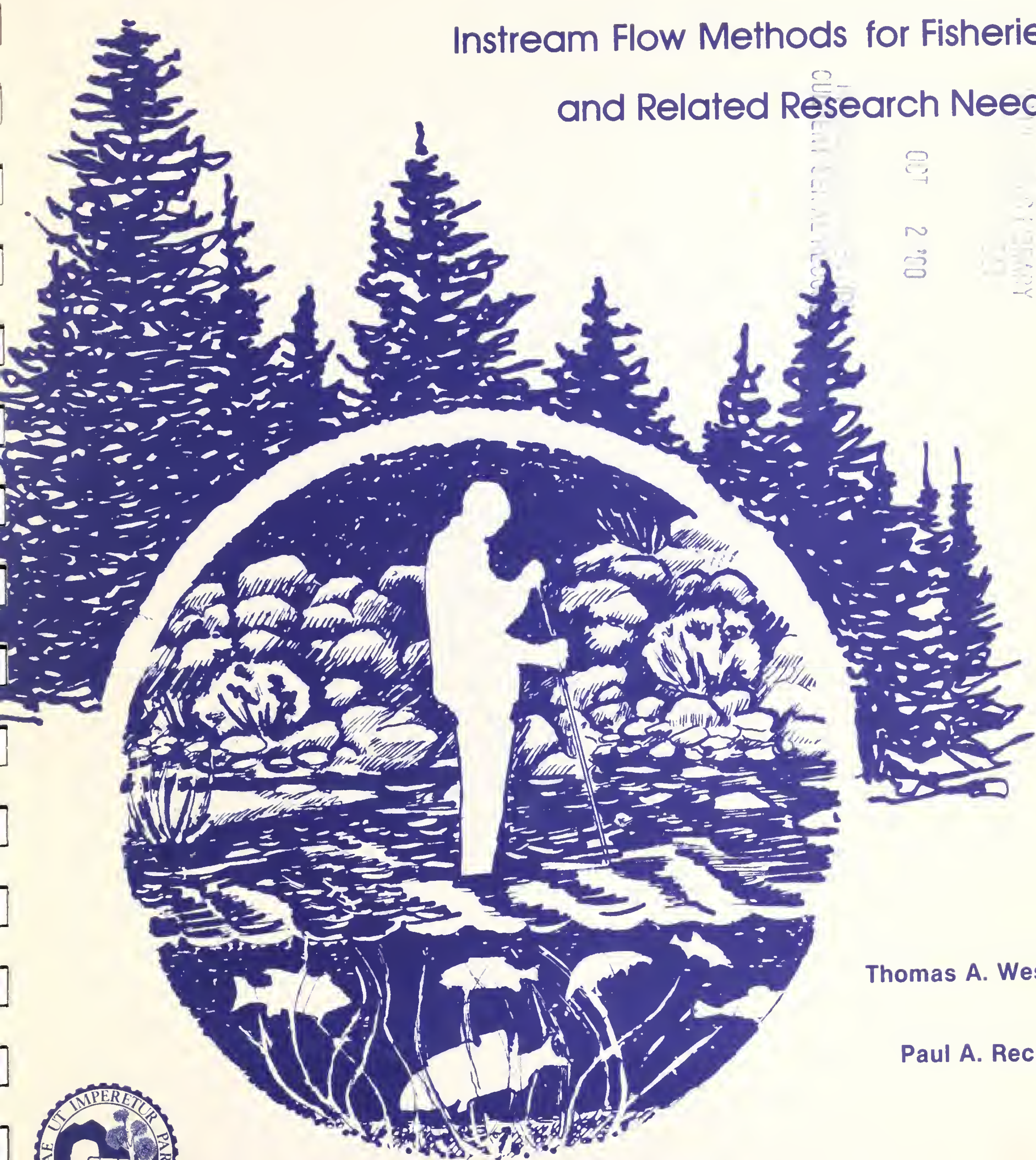
Eisenhower Consortium Bulletin 9

# A Summary of Instream Flow Methods for Fisheries and Related Research Needs



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## Foreword

Methodologies for determining instream flow needs are developing at a great rate. To comply with legislative requirements and regulatory procedures, every state and federal agency concerned with land and water utilization and environmental quality protection must develop riparian management plans. The basis for these plans is data on instream flow needs, especially the flow needs of stream fisheries. These data are being developed through the development and use of a variety of procedures, some of which may not be applicable to the job at hand.

The Rocky Mountain Forest and Range Experiment Station, cooperating with other units of the USDA Forest Service, the USDI Bureau of Land Management and Fish and Wildlife Service, and the Colorado Division of Fish and Game, undertook a cooperative effort with the Eisenhower Consortium for Western Environmental Forestry Research to evaluate current instream flow measurement procedures related to fisheries management. A research team of scientists from the Rocky Mountain Station, the University of Wyoming, Colorado State University, Arizona State University, and the University of New Mexico conducted the original analyses; scientists at the University of Wyoming completed the work and prepared the report.

This bulletin presents methodology currently available for determining instream flow needs for fisheries management in the Rocky Mountain West. The procedures described are probably applicable to measuring streamflow needs in many other areas of the nation as well.

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# A Summary of Instream Flow Methods for Fisheries and Related Research Needs

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Contents

## PROLOGUE

### Introduction

During the decade of the 1970's, the instream flow field has been in a constant state of evolution. Evidence of this dynamic character is apparent to any practitioner who has attempted to remain current with the ever-increasing wealth of available literature.

Since the initial writing of this paper in late 1975 and early 1976, numerous advancements in the field have been made. Certain methodologies have been improved and expanded while others have become outdated and their usefulness lessened. Computer software for hydraulic simulation and data handling has become more abundant and more sophisticated. Attempts have been made to standardize the techniques used to collect basic field data. The quantity and quality of fish habitat criteria have continually been on the rise. Research has been ongoing to address critical problems such as the ecosystem response to flow alteration and the seasonal variability of habitat occupation by fish. Continuing attention has been given to the recommendation of suitable flow regimes to maintain habitat on both a seasonal and a species basis rather than the recommendation of a single "minimum flow" value.

Given the ever-changing nature of the "state-of-the-art" and the inherent lag time between completion of a paper and publication, the decision was made that this Prologue be added to the original work. The purpose herein will be to succinctly inform the reader of recent developments regarding instream flow methodologies and related research. Due to the time constraint involved, this chapter is not intended to be a comprehensive state-of-the-art document.

### General Overview

While the early to middle years of the 1970's can be considered a developmental period for a variety of instream flow methodologies, the latter years of the decade can be characterized primarily as a period of methodology testing, standardization and refinement. Two significant events served as the dividing point between the two periods. First was the Symposium and Specialty Conference on Instream Flow Needs presented by the Western Division of the American Fisheries Society and the Power Division of the American Society of Civil Engineers from May 3-6, 1976, in Boise, Idaho. While this conference was not the first to draw together practitioners in the field from all corners of the United States, it did provide the first nationwide forum seeking solutions to the technical, legal and social problems stemming from increasing competition for limited streamflow. Workers in the instream flow field not only discussed their various methodologies with an interdisciplinary audience (including water administrators, lawyers, and engineers among others), but in turn, listened to the oftentimes differing viewpoints expressed by such a mixed audience regarding the allocation of the resource.

The second key event was the formation and initiation of staffing of the Cooperative Instream Flow Service Group (CIFSG) in Fort Collins, Colorado, during July 1976. The specific objectives which the CIFSG was created to fulfill are (from CIFSG, 1979):

1. "to develop improved methods for assessing and predicting instream flow requirements for fish, wildlife, other aquatic organisms, recreation, and aesthetics (Methodologies);"

2. "to develop guidelines for implementing instream flow recommendations (Strategies);"

3. "to establish an effective communication network for disseminating instream flow information (Information Management System)."

These objectives have been well met by the Group over the past three years.

If the specialty area of instream flow was considered a wheel, the CIFSG would be its hub. While providing service to a variety of federal, state and local agencies, the Group has become the center of activity in terms of methodology development and refinement, strategy development for obtaining instream flows, and, information management and transfer. To familiarize the reader with the depth and breadth of the Group's involvement in the field, Table P-1 presents a list of the Instream Flow Information Papers published since 1976. Table P-2 contains a listing of articles and papers prepared by CIFSG personnel. The work of the Group as it relates to instream flow needs for fisheries will be discussed in greater detail later in this chapter.

Evidence of the ever-increasing national importance of maintaining instream values was provided by President Carter during 1978. On June 6, 1978, the President sent his Water Policy Initiatives to Congress. A month later,

Table P-1. Instream flow information papers published by the Cooperative Instream Flow Service Group, 1977-1979.

1. Lamb, Berton Lee, Editor. Guidelines for Preparing Expert Testimony in Water Management Decisions Related to Instream Flow Issues. Fort Collins, Colorado, Cooperative Instream Flow Service Group, July 1977, 30 pages. FWS/OBS-77/19. (NTIS Accession Number: PB 268 597; Library of Congress Catalog Card No. 77-63281.) 1300 printed - out of print.

1. (Revised) Lamb, Berton Lee, Editor. Guidelines for Preparing Expert Testimony in Water Management Decisions Related to Instream Flow Issues. Revised. Fort Collins, Colorado, Cooperative Instream Flow Service Group, 1979. FWS/OBS-79/37. In press.

2. Lamb, Berton Lee, Editor. Protecting Instream Flows Under Western Water Law: Selected Papers. Fort Collins, Colorado, Cooperative Instream Flow Service Group, September 1977, 60 pages. FWS/OBS-77/47. (NTIS Accession Number: PB 272 993; Library of Congress Catalog Card No. 77-15286.) 300 printed - out of print.

3. Bovee, Ken D., and Tim Cochnauer. Development and Evaluation of Weighted Criteria, Probability-of-Use Curves for Instream Flow Assessments; Fisheries. Fort Collins, Colorado, Cooperative Instream Flow Service Group, December 1977, 49 pages. FWS/OBS-77/63. (NTIS Accession Number: PB 286 848.) 1400 printed - out of print.

4. Bovee, Ken D. Probability-of-Use Criteria for the Family Salmonidae. Fort Collins, Colorado, Cooperative Instream Flow Service Group, January 1978, 88 pages. FWS/OBS-78/07. (NTIS Accession Number: PB 286 849.) 700 printed - out of print.

5. Bovee, Ken D., and Robert T. Milhous. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Fort Collins, Colorado, Cooperative Instream Flow Service Group, May 1978, 129 pages. FWS/OBS-78/33. (NTIS Accession Number: PB 287 015; Library of Congress Catalog Card No. 78-600110.) 900 printed - 765 distributed.

6. Hyra, Ronald. Methods of Assessing Instream Flows for Recreation. Fort Collins, Colorado, Cooperative Instream Flow Service Group, May 1978, 49 pages. FWS/OBS-78/34. (NTIS Accession Number: PB 285 967; Library of Congress Catalog Card No. 78-600071.) 900 printed - 779 distributed.

6. (Revised) Hyra, Ronald. Methods of Assessing Instream Flows for Recreation. Revised. Fort Collins, Colorado, Cooperative Instream Flow Service Group. FWS/OBS-79/38. In press.

7. Bayha, Keith. Instream Flow Methodologies for Regional and National Assessments: A State-of-the-Art Review. Fort Collins, Colorado, Cooperative Instream Flow Service Group, December 1978, 130 pages. FWS/OBS-78/61. In press.

8. Pruitt, Thomas A., and Richard L. Nadeau. Recommended Stream Resources Maintenance Flows on Seven Idaho Streams. Fort Collins, Colorado, Cooperative Instream Flow Service Group, July 1978, 58 pages. FWS/OBS-78/68. (NTIS Accession Number: PB 287 849.) 900 printed - 332 distributed.

9. Wassenberg, P. S., Stewart Olive, Janet L. DeMott, and Clair B. Stalnaker. Elements in Negotiating Stream Flows Below Federal Projects. Fort Collins, Colorado, Cooperative Instream Flow Service Group, August 1979, 75 pages. In press.

10. Sweetman, Debra A. Protecting Flows in Montana: Yellowstone River Reservation Case Study. Fort Collins, Colorado, Cooperative Instream Flow Service Group. FWS/OBS-79/36. In press.

Source: Cooperative Instream Flow Service Group, 1979.

Table P-2. Articles and papers by Cooperative Instream Flow Service group personnel, 1977-1979.

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PHABSIM System for Instream Flow Studies--Proceedings of the 1979 Summer Computer Simulation Conference. Robert T. Milhous.

"The Use of Habitat Structure Preferenda for Establishing Flow Regimes Necessary for Maintenance of Fish Habitat." In The Ecology of Regulated Streams, J. V. Ward and J. S. Stanford (Eds.) Plenum Publ. Corp. N.Y. 1979. C. B. Stalnaker.

"Managing the Ripling Stream: A Model of Decision-Making in Natural Resource Administration." Water Resources Bulletin, Vol. 15, No. 6, December 1979. Harvey R. Doerkson and Berton L. Lamb.

"Computer Simulation--A Means of Developing an Aquatic Mitigation Plan." National Mitigation Symposium, Colorado State University, Fort Collins, Colorado, July 14-16, 1979. David L. Wegner.

"New Opportunities on the Horizon." National Mitigation Symposium, Colorado State University, Fort Collins, Colorado, July 14-16, 1979. Keith Bayha.

"Keeping Water in the River." Seminar on Natural Resources Law and Management, University of Colorado Law School, Boulder, Colorado, December 1978. Berton L. Lamb.

"The IFG Incremental Methodology for Physical Instream Habitat Evaluation." Proceedings of a symposium, Surface Mining and Fish/Wildlife Needs in the Eastern United States. FWS/OBS-78/81, pp. 126-135, December 1978. Clair B. Stalnaker.

"Stream Habitat and Its Physical Attributes as Linked to Water and Land Management." Proceedings of the High Mountain Watershed Management Workshop, Utah State University, Logan, Utah, December 7, 1978. Clair B. Stalnaker.

"Methodologies for Preserving Instream Flows, The Incremental Method." Proc. Symposium Upper Mississippi River Basin Comm., November 14, 1978. Clair B. Stalnaker.

"The Stochastic Variation of Instream Values in Rivers." Verification of Mathematical and Physical Models in Hydraulic Engineering, ASCE, August 1978. Robert T. Milhous and Ken D. Bovee.

"Estimation of Diffuse Loading of Water Quality Pollutants by Kalman Filtering." American Geophysical Union Chapman Conference on Applications of Kalman Filters to Hydrology, Hydraulics, and Water Resources, Pittsburgh, Pennsylvania, May 1978. David S. Bowles and William J. Grenney.

"The Interaction of Stream Flow Alterations, Stream Habitat, and Channel Morphology." Presented to the Pacific Fishery Biologists' 40th Annual Meeting, Konocti Harbor Inn, California. Robert T. Milhous.

"The Incremental Method of Assessing Habitat Potential for Coolwater species, with Management Implications." AFS Symposium on Coolwater Fishes, March 7-9, 1978, Minneapolis, Minnesota. Ken Bovee.

"Steady-State River Water Quality Modeling by Sequential Extended Kalman Filters." Water Resources Research, 1978. D. S. Bowles and William J. Grenney.

"Field Testing and Adaptation of a Methodology to Measure Instream Values in the Tongue River, Northern Great Plains Region." U.S. Environmental Protection Agency, Denver, Colorado. K. D. Bovee, J. A. Gore, and A. J. Silverman. 1977.

"Comparative Evaluation of Four Instream Flow Methodologies on the Yampa and White Rivers in Western Colorado." U.S. Bureau of Land Management, December 1977. Charles G. Prewitt.

Table P-2. (continued)

Editorial presentation of "Water Resources Management: A Symposium." Public Administration Review, November 5, 1977 (Lamb co-editor).

"Methods for Calculating Instream Flow Needs." American Water Resources Association, Tucson, Arizona, October 13-November 3, 1977. Ronald Hyra and James Scott.

"Instream Flow Requirements and Stream Morphology." American Water Resources Association, Tucson, Arizona, October 1977. Robert T. Milhous and Ken D. Bovee.

"Hydrology and Instream Flow Water Management." American Geophysical Union, Portland, Oregon, September 29-30, 1977. Robert T. Milhous.

"The Transfer of Water Resources Management Information--The Cases of the Washington State Department of Ecology and the Cooperative Instream Flow Service Group." Second International Conference on Transfer of Water Resources Knowledge, Colorado State University, Fort Collins, Colorado, June 30-July 2, 1977. Robert T. Milhous.

"Drowning in Data?" Second International Conference on Transfer of Water Resources Knowledge, Colorado, June 30-July 2, 1977. David C. Flaherty.

"Water Allocation and Instream Uses." National Conference on Water, St. Louis, Missouri, May 23-25, 1977. Clair B. Stalnaker and William H. Honore.

"Water Supply vs. Recreation and the Fishery--Minimum Stream Flows." American Waterworks Association, 1977 Annual Meeting, May 9, 1977. Robert T. Milhous.

"A Tale of Two Rivers: Agency Behavior in Establishing Instream Flows." American Society for Public Administration, Atlanta, Georgia, March 31, 1977. Berton L. Lamb.

"Water: The Next National Crisis?" Outdoor Recreation Action, Spring 1977. Keith D. Bayha and William H. Honore.

"Abstraction, Appropriation, and Instream Flow Needs." Fisheries, Vol. 2, No. 1, January-February 1977. Clair B. Stalnaker.

Source: Cooperative Instream Flow Service Group, 1979.

on July 12, 1978, the President Issued 13 memoranda to federal agencies to begin implementation of his Water Policy. As a result of these directives, 19 task forces were created, one of which was given the responsibility of instream flows. Six major tasks were addressed by the Instream Flow Task Force, as listed in Table P-3 with the title of the coinciding report generated (Interagency Task Force - Instream Flows, May 1979).

While the scope of the Interagency Task Force effort was not to develop detailed methodology to deal with the specific flow requirements of all instream uses in all situations, their work is worthy of mention in this paper from the broader water planning aspect. The information contained in the report entitled, "Guidelines for determining instream flow needs," was designed for application primarily in the early stages of the water planning process by the water-development agencies. Too often in the past consideration of instream values has been only "tacked-on" to the final stages of a project, if at all. The Task Force report stresses the need for inclusion of instream values as a planning goal in the preliminary planning stages. Also stressed is the need to identify alternative approaches to meet such goals early in the planning process. To assist the water planner, the Interagency Task Force prepared a matrix describing the general characteristics required for a variety of instream uses (including recreation, water quality, aesthetics, fish and wildlife habitat, flood control, navigation and hydropower). That portion of the matrix dealing with fish and wildlife is reproduced in Table P-4. Based upon this matrix, the Task

Table P-3. Tasks addressed and reports issued by the Instream Flow Interagency Task Force.

| Title | Task |
|---|---|
| Federal Assistance Available to the States on Ground-Water Supply and Instream Flows | Advise the 50 State Governments of the President's instream flow directive; willingness of the Federal Government to cooperate; types of technical assistance, data, and information available; and how to obtain. |
| General Review of Planning Procedures of Water Resources Development Agencies | Request Federal water-resource planning agencies to review their procedures to insure their planning procedures provide for the maintenance of adequate instream flow below proposed dams and other water-resource control facilities and, if not, to amend their procedures accordingly. |
| Guidelines for Determining Instream Flow Needs | Develop guidelines to determine instream flow for water quality, aesthetic, fish, wildlife, and recreation values. |
| Identification of Existing Federal Water Resources Development Projects Where Instream Flow Uses Could Be Improved | Request agencies to identify, in cooperation with the States: a) existing projects where instream flow is a problem, b) corrective measures agencies plan to take, such as operation and management techniques or legislative actions, and c) when the corrective measures will be taken or techniques implemented. |
| Federal Legislation for the Protection and Maintenance of Instream Flows | Identify legislation that provides general authority to agencies to protect and maintain instream flow and advise agencies. |
| Need for Legislative Amendments to Existing Water Resource Project Legislation | Request water planning agencies to review existing authorizations to determine if the agency has adequate legislative authority to maintain instream flow at existing facilities. Where there is not adequate authority and where commitments and economic feasibility permit, the agency, in cooperation with the affected State, shall develop legislative amendments to correct the situation. |

Source: Instream Flow Interagency Task Force, 1979.

Table P-4. Characteristics required for instream uses.

| Use | Minimum | Maximum | Optimum | Flow Variability | Other |
|---|---|---|---|---|---|
| Fish and Wildlife Habitat | | | | | |
| Fishery maintenance | That flow which produces depth, velocity, temperature, and substrate configurations that permit continued life functions of selected species, such as egg production, rearing of juveniles, and migration. | That flow which produces velocity and depth at the upper range of species tolerance or which results in scouring of egg deposits or change in channel structure. | That flow which maximizes habitat, expressed in terms of an acceptable range of depth, velocity, substrate, temperature, and wetted perimeter for selected species. | Seasonable fluctuation desirable to maximize available habitat for various life stages. Daily or short-term fluctuation can cause stranding of individuals and eggs. Rapid fluctuations can cause undesirable channel change and substrate shifting. | |
| Wildlife habitat | That flow which is sufficient to maintain a desired streamside vegetation and instream flow sufficient to maintain crucial biological functions. | That flow above which scouring, deep erosion, and loss of streamside vegetation will result. | That range of flows within which streamside vegetation is maintained and water habitat is sufficient for crucial biological functions. | Seasonal variation in flows is acceptable, provided that duration of flooding is not sufficient to kill streamside plants. Rapid daily fluctuations are not desirable because they cause heavy erosion of streambank resulting in loss of vegetation. | |
| Water Quality | | | | | |
| Protection and propagation of fish and shellfish (freshwater) | Amount specifically required for maintenance of desired balance and species. | | Amount specifically required for propagation of desired balance and species. | Seasonal variation to satisfy life functions. Instantaneous change of flow rate to be limited to protect desired ecosystem. | Seasonal temperature should be within the range of life-cycle requirements. |
| Protection and propagation of fish and shellfish (saline water) | Amount necessary to control location of saline gradients. | Amount necessary to control location of saline gradients. | Amount necessary to control location of saline gradients. | Amount required to assure proper saline gradients under seasonal requirements. | |
| Protection of wildlife habitat | Amount necessary to maintain the watering source. | | | Seasonal variation to satisfy life functions. Instantaneous change of flow rate to be limited to protect existing ecosystems. | |

Source: Instream Flow Interagency Task Force, 1979.

Force then illustrated the logical sequence of thought for preparing instream flow recommendations for use in water-resource project planning, as shown in the flow chart presented in Figure P-1. The left side of the chart presents a possible approach for applying instream-flow guidelines to planning, while the right side lists the planning steps recommended by Principles and Standards.

Figure P-1 is included here in the Prologue to supplement the planning guidance provided by Figures 1 and 2 in the Preface of this report. The remaining portions of this Prologue will serve to update the reader regarding recent developments in the field of instream flow fisheries methodology and related research. As such, the following three areas will be addressed:

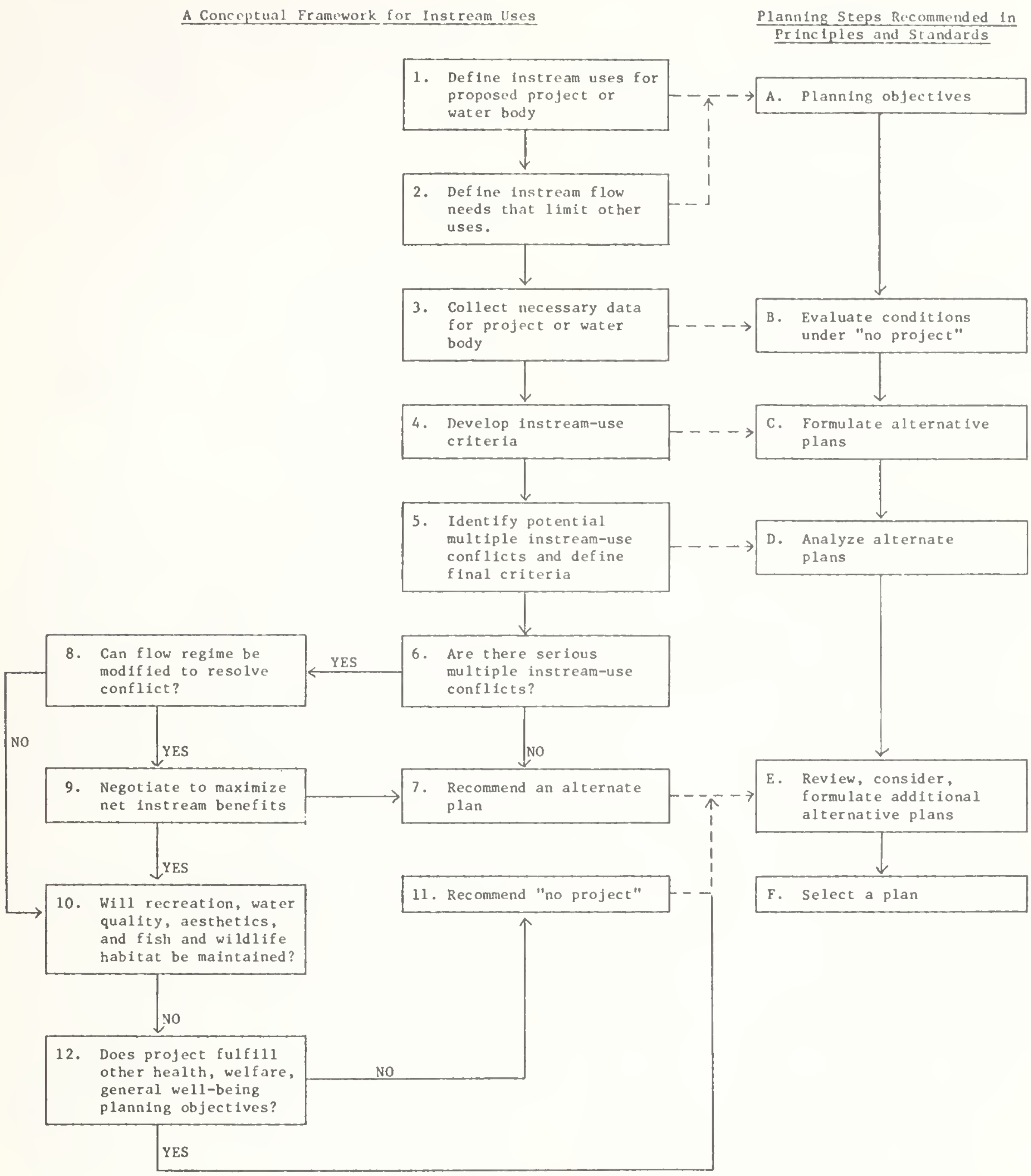
--Modification and improvement of methodologies.

--Testing and comparison of methodologies.

--Related research.

## Modification and Improvement of Methodologies

Sixteen methodologies have been described in the body of this report. Of these, several are no longer in use as improved methods have become available. The CIFSG concurs that the following methodologies are the predominant methods being used at present in the western United States: Tennant, 1976; Northern Great Plains Resource Program (NGPRP), 1974; Hoppe, 1975; USFS Region 1, Region 2 Cross, and Region 4 methods for streams having low roughness coefficients; Waters, 1975 (California Method); Collings, 1974 (Washington Method); Thompson, 1972 as modified in Pruitt




(Source: Modified from Interagency Task Force-Instream Flows, May 1979)

Figure P-1. Use of criteria for developing instream flow recommendations.

and Nadeau, 1978 (Oregon Method); Wesche, 1973 and 1974, for smaller brown trout streams where cover is critical; and CIFSG's Incremental Method (Clair B. Stalnaker[1], personal communication to Gordon D. Lewis[2], December 21, 1979). The first three methods listed above are generally considered "office" methods (i.e., recommendations can be obtained with no field visits) and would be most useful for reconnaissance grade, planning level, studies. The remaining eight methods are based upon the collection of varying amounts of field data and are most applicable at the project level for site specific studies.

Following is a summary, by method, of modifications and improvements which have been made over the past several years. Failure of a method to appear below indicates that the method has remained basically unchanged from that described in the body of this report.

Tennant Method (Tennant, 1976)

The Tennant Method has remained relatively unchanged since 1976 (Donald Tennant[3], personal communication, February 1980). This quick, easily applied method remains one of the most often used, especially for broad scale studies such as regional planning. The Bureau of Land Management (BLM) "suggests" the use of this method for reconnaissance level surveys in its recently released "Instream Flow Guidelines" (U.S. Department of the Interior, June 1979). While the BLM does not recommend this method for site specific studies, the "Guidelines" caution that if the method must be used in such circumstances due to time and/or personnel constraints, the following limitations should be recognized: (1) as the method is based entirely on mean annual flow ("average discharge"), flow fluctuations and/or seasonal variability are not accounted for; (2) the method is best suited for large stream systems which normally have less flow variability than do small streams; (3) the method does not account for stream channel geometry; and (4) the recommendations based on the method should be compared with the average 10-day and 30-day natural low-flow values.

[1]CIFSG, Ft. Collins, Colorado.

[2]Rocky Mt. Forest and Range Exp. Station, Ft. Collins, Colorado.

[3]USFWS, Billings, Montana.

In discussing the Tennant Method with practitioners in the instream flow field, it appears that a certain amount of confusion has arisen regarding its application. At no time does Tennant (personal communication, February 1980) recommend that 10 percent of average flow be considered a reasonable instream flow recommendation for Class I, II and III streams (see Table 2, page 19). It is unfortunate that the descriptor "minimum" was selected as the narrative description of "10 percent average flow." This terminology, coupled with the often incorrectly used term "minimum flow," has led to the misunderstanding. To correctly apply the Tennant Method, the practitioner is cautioned to thoroughly review Tennant's 1976 paper and to not rely solely on the description presented in the table entitled "Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources."

A modification of Tennant's Method was reported by Bayha (1978) in the report entitled, "Instream Flow Methodologies for Regional and National Assessments." In determining instream flow approximations (IFA's) for certain ASR's (assessment subregions), those generally in the "midwestern" portion of the United States, it was felt that spring runoff flows were especially important to clean spawning gravels, recharge wetlands, and facilitate fish spawning migrations. Therefore, to provide these flushing flows, 100 percent of the average annual discharge was recommended during the normal spring runoff months, instead of the 60 or 40 percent levels.

A second modification of Tennant's Method reported by Bayha (1978) concerned the streams of the irrigated West where transbasin diversions, water storage and use of grounwater were significant. Due to such development and the subsequent effects on streamflow, it was deemed necessary that a "surrogate" be developed for the mean annual flow. Such surrogates were termed Natural Modified Flows (NMF's) and defined as "the estimated mean streamflow without offstream depletions but with present conditions of storage, reservoir evaporation, and operation at the principal point(s) of discharge from the ASR." To calculate NMF, the following equation was developed:

$$NMF = PMF + \Sigma(USEp - Ip + Ep - GWMp)$$

where:

PMF (Present Modified Flow) is the mean flow determined to exist with the 1975 level of development (later termed "Current Streamflow")

$\Sigma$(USEp - Ip + Ep - GWMp) is the sum of current depletions from NMF for a given ASR and all upstream ASR's

USEp is the term used to identify the actual water consumption calculated for 1975

GWMp is the present estimated groundwater mined (withdrawn from deep aquifers without recharge)

Ep is present total export

Ip is present total import

The NMF's were then used in place of mean annual flow values (average discharges) as the basis upon which to calculate the IFA's using the Tennant Method.

Practitioners involved in reconnaissance studies are urged to review Bayha (1978) carefully. The paper provides numerous examples of how planning level methodologies can be modified to allow consideration of the unique flow characteristics of various sub-regions within a larger planning region.

Further modifications were applied to the Tennant (Montana) method by personnel of the Water Resources Research Institute, South Dakota State University as part of a study of the "Reconnaissance Elements of the Western Dakotas Region of South Dakota." Following is a summary of the modifications (From Tessman, 1980):

"Recognizing the importance of flow cycles and silt load, several modifications were applied to the Montana Method. The following assumptions accompanied modifications:

1. Living components of stream ecosystems are adapted to the natural flow regime and depend both on high flows and periods of low or even zero flow to satisfy all requirements of their life cycles. The best minimum flow model is one that mimics nature. Hence, minimum flow values should parallel the natural flow regime during the yearly cycle.

2. Low flow periods are necessary for certain stages of life cycles of some organisms, but are critical periods of stress for many other aquatic animals. The few adults that survive in isolated pools may be the only breeding stock to replenish the population when water conditions improve. It is therefore assumed that streams are more sensitive to abstraction during periods of low flow than at other times of year. The mean monthly flow was chosen as a level beneath which no water should be removed during months of low flow."

"By Tennant's method, the year is divided into two six-month periods, April through September and October through March. Percentages of mean annual flow are specified during each period, the October-March flow being a lower value. Percentages are chosen based on narrative descriptions of environmental quality and desires of the party determining instream needs. Excellent conditions are maintained for fish, wildlife, and recreation at 30% and 50% of mean annual flow during the October-March and April-September periods, respectively. These periods do not correspond well to flow periodicity in prairie streams, however. March is typically the month of greatest runoff but falls within the period of lower flow percentage. High flows in March are important for flushing of silt. Further, the 30% flow level exceeds average monthly flows during most of the low water months. Fluctuations in the Black Hills streams are not as severe, but are such that the same problems occur on a lesser scale."

"Extreme fluctuations in periodicity are accommodated by applying a compromise value of 40% on a monthly basis, with some stipulations. During low water months, when the mean monthly flow is less than 40% of mean annual, the mean monthly flow is designated as the minimum flow. This preserves flow of low water months. Since a mean flow value is used, there will obviously be months when the actual runoff is less than mean runoff. The mean monthly flow simply serves as a constraint to indicate that no water may be abstracted if actual flow is equal to, or less than the mean flow. It is not a specification that the minimum flow must be maintained at the mean monthly flow because flows of this magnitude cannot be expected in most years. If the mean monthly flow exceeds 40% of the mean annual, but 40% of the mean monthly is less than 40% of the mean annual, then 40% of mean annual is designated as the minimum monthly flow. If 40% of mean monthly exceeds 40% of mean annual, then minimum monthly is 40% of mean monthly. A summary of this procedure follows:

| Situation | Minimum Monthly Flow |
|---|---|
| 1. mean MF <40% mean AF | mean MF |
| 2. mean MF >40% mean AF and 40% mean MF <40% mean AF | 40% mean AF |
| 3. 40% mean MF >40% mean AF | 40% mean MF |

MF = Monthly Flow

AF = Annual Flow

"Further, a 14-day period of 200% of mean annual flow is specified during the month of highest runoff for purpose of flushing the stream's silt load and flooding streamside habitat. By using this modified procedure, the annual periodicity may be mimicked without gross over appropriation of flow that would result by strict application of the Montana Method."

USFS Region 2 Cross Method

This method, also termed the "Sag Tape" and the "Critical Area" method, continues to be used extensively in USFS Regions 1 and 2. Since 1976, several modifications and variations of the basic method have evolved. These are reported herein.

Eddie Kochman[4] of the Colorado Division of Wildlife (CDW) reports that the CDW has continued to use the R-2 Cross Method for the majority of its instream flow determinations (Kochman, personal communication, February 1980). The major modification to the method is the inclusion of formulae developed by Lee Silvey[5] (USFS Region 2 Regional Hydrologist) for estimating Manning's "n" at synthesized water stages based upon field measured data. Silvey (personal communication, February 1980) reports that while this research is still in the experimental phase and unpublished, the following basic formula could be included here:

$$n_2 = \frac{1/\sqrt{R_2}}{1/\sqrt{R_1}} \times n_1$$

where:

$n_2$ = "n" for the predicted discharge

$R_1$ = hydraulic radius associated with the field measured discharge

$R_2$ = hydraulic radius associated with any other predicted discharge

$n_1$ = "n" value from field measured discharge

In field tests of this formula on Routt National Forest in northern Colorado a good relationship was found between the predicted "n" values and those field measured. The major problem at present appears to be in the reproducibility of the results. However, both Silvey and Kochman feel that the results are encouraging and that the formula should be applied in the R-2 Cross program, rather than let "n" remain constant over the range of synthesized water stages. Other than this modification, the CDW's use of the R-2 Cross method remains basically the same as that described in the text of this paper.

Boaze and Fifer (1977) applied a modified version of the Region 2 (Critical Area) method to make instream flow determinations for the Hunter Creek drainage within White National Forest, Colorado. Subsequently termed the "Hunter Creek Method," this methodology included the selection of several critical area transects per study site, with field data collection over a range of flow conditions. Thus, computer simulation of various water stages was not involved. Also, each of the transects selected and sampled at each site was felt to be representative of at least one of the habitat types necessary for trout production (i.e., food production, cover, and spawning areas and fish passage). Hydraulic measurements were made at each transect at seven different flow levels. Habitat criteria, in terms of water velocity, depth and wetted perimeter, were then selected for use from the literature and from discussions with other fisheries biologists knowledgeable about the study streams. Values were selected based upon trout size, species present, and spawning requirements. The hydraulic criteria (average depth, velocity and wetted perimeter) were considered to be of equal importance. Because of the close relationship between these criteria, it was decided that the recommended flow should meet at least two of the three.

It is obvious from the above discussion that the "Hunter Creek Method" would be far more expensive, in both financial and manpower terms, than would the method as applied by CDW. The question of the value of such additional expense in terms of the quality and precision of the instream flow recommendation will be considered in the following section of this Prologue, entitled "Testing and Comparison of Methodologies."

Jespersen (1979, 1980) reports on another variation of the R-2 method applied to a number of small mountain streams in the Medicine Bow National Forest of southeastern Wyoming. The methodology as applied by Jespersen can best be described as a synthesis of the R-2 Cross method as applied by CDW and

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[4]Denver, Colorado.

[5]Denver, Colorado.

the "Hunter Creek Method" (HCM). Several transects were sampled for hydraulic characteristics at each study site as in the HCM. However, due to the number of streams and sites involved, data collection could only be conducted at one flow (a low late summer level). Hence, the R-2 Cross computer program, based upon Manning's equation, was used to define the hydraulic characteristics at the transects at a variety of water stages other than that field measured. Wesche et al. (1977) used a technique very similar to Jespersen's at the same locations on many of the same streams. It is of interest to note that the results of the two independent investigations were exceptionally close. This will be discussed further in the next section.

The BLM suggests the use of a single transect method very similar to that utilized by the CDW for intermediate-level efforts ("intermediate" in terms of data collection intensity). While the Bureau recommends that a multiple transect method be used whenever its claims would be questioned and carefully examined in a court of law, the single transect method could be used in less controversial situations. Examples would be in general State court water adjudications or in administrative proceedings where a large number of streams must be quantified and serious legal opposition is not a possibility (U.S. Department of the Interior, 1979).

As with the CDW method, a qualified fisheries biologist should select the critical area to be sampled by the single transect. Once the appropriate measures are made in the field at the one flow level, one suggested method to complete the data synthesis is the Manning's equation approach. The computer program to be used is termed FISHFLO and is based in part on the R-2 Cross program. A procedure is included which will allow for adjustments in either slope or Manning's "n." Also, with FISHFLO there is no need to level the cross section end stakes.

A second possible technique for data synthesis suggested by the BLM is the stage-discharge appropach. This approach requires that the hydrologist on the study team establish a hydraulic reference station, consisting of a staff gage, water level recorder or other such instrumentation for monitoring water level, at a suitable site. A stage-discharge relationship is then determined by a series of stage-discharge measurements and can be used to examine the relationship between hydraulic variables (fish habitat) and discharge.

Although the stage-discharge approach overcomes several of the accuracy problems inherent with the Manning's equation approach (i.e., varying "n" and slope with discharge), it does require considerably more field time. The BLM cautions that the hydrologist must carefully consider both time constraints and accuracy before deciding between the two procedures.

The CIFSG has also developed a modified version of the R-2 Cross computer program, termed IFG-1 (Bovee and Milhous, 1978). This program, based upon Manning's equation assuming uniform flow, predicts depth and velocity distributions in conjunction with single transect methods. The primary difference between R-2 Cross and IFG-1 is that IFG-1 outputs widths of streams having specified depth.

### USFS Region 4 Method

Since the initial preparation of this report, the various components of the Region 4 method have been brought together and published under separate cover. While the basic method has remained the same, the report, entitled "Procedural Guidelines for Instream Flow Determinations" by Tew et al. (1977), helps to clarify the use of the method. While it is not necessary to repeat the detailed procedures involved, the "Problem Analysis Steps" identified by Tew et al. are of value. These are as follows:

"1. Establish forest priorities for evaluating instream flow needs."

"2. Prepare appropriate maps showing land ownership patterns including reserved lands, acquired lands, and alienated lands where instream needs are being evaluated. Reservation dates should be shown for all reserved lands."

"3. Identify points where diversions have been or will be made in the foreseeable future that involve reserved and/or appropriative rights of the United States and appropriative rights of others."

"4. Establish interdisciplinary study team with appropriate specialists."

"5. Determine season of use and quantities of water being diverted."

"6. Determine instream flow uses by season."

"7. Identify data base available for analysis of streamflow and flow related values.

"8. Determine the range in and seasonal distribution of streamflow by making appropriate measurements or by making estimates based on available records."

"9. Identify critical channel sites and establish master reference stations."

"10. Develop criteria for evaluating instream flow requirements."

"11. Select methodologies for evaluating streamflow and flow related qualities."

"12. Evaluate seasonal flow alternatives considering water availability and the social and economic values associated with required instream flows."

"13. Develop a schedule of flows required to meet National Forest needs at each reference station."

"14. Prepare instream flow inventory Form R4-2500-23a for submission to the Regional Office."

### Oregon Method

A modification of the Oregon Method was made by Pruitt and Nadeau (1978) in a report entitled, "Recommended Stream Resource Maintenance Flows on Seven Southern Idaho Streams." While the field techniques applied were unchanged from those of the Oregon Method, the spawning habitat criteria applied to the data were modified. Rather than using the typical unweighted criteria, the weighted criteria developed for depth and velocity parameters by the CIFSG were applied. The spawning flow recommendations were then based on the concept of electivity curves. According to Bovee and Cochnauer (1977), the "...curves are based on the assumption that the individuals of a species will tend to select areas within the stream having the most favorable combinations of hydraulic conditions. It is further assumed that they will also utilize less favorable conditions, with the probability-of-use decreasing with diminishing favorability of one or several hydraulic conditions. Finally, it is assumed that individuals will elect to leave an area before conditions become lethal. The weighted criteria are presented in the form of [electivity] curves, the peak of which represents optimum conditions for a given hydraulic parameter."

To make use of the weighted criteria, Pruitt and Nadeau report that, "Each spawning transect was segmented into at least 10 sections. The weighted value of each segment was determined by multiplying the width of the segment by the weighted value for depth and velocity. The total weighted value for the transect is the total of the transect segments. Each total weighted value was then plotted against the corresponding discharge resulting in a curve...."

The development of the electivity curves has been a high priority task for the CIFSG. While this work will be discussed later, it should be pointed out here that weighted criteria are being applied more and more in conjunction with instream flow methodologies. Assuming that the curves are based upon valid habitat data, their use should lend additional biological sensitivity to the recommendations.

### CIFSG Incremental Method

As previously stated, the CISFG[6] has been the center of activity in the specialty field of instream flow since its inception in 1976. The list of CIFSG publications and presentations has been provided to illustrate the depth and breadth of the Group's work in the field. The intent of this Prologue is to keep the reader abreast of the advances being made in the area of fisheries methodology, not to provide a reiteration of detailed methodology. Information transfer is an important task of the CIFSG. Practitioners in the field are strongly urged to keep an up-to-date set of the Instream Flow Information Papers on their bookshelves.

The integral subset of the large system collectively called the "CIFSG Incremental Method" of primary interest to fishery biologists is the Physical Habitat Simulation System (PHABSIM). PHABSIM, by definition is "a method of evaluating the availability of physical microhabitats in streams under different conditions of discharge and channel configuration" (Bovee et al., 1979). The basic method has been described in the body of this paper.

During the past two years, the CIFSG (1979) reports that the Incremental Method has been applied 452 times by its clients. While the predominant use has been for quantification of instream flow needs for protection under state or federal law (62 percent), the

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method has also been applied for area-wide planning, negotiation of water releases, and impact analysis. In regard to the geographical distribution, the greatest intensity of application has been in the western United States, although substantial use has been made in the east.

The BLM has recently recommended the Incremental Method as the multiple transect method to be used for situations which might involve legal or political challenge or when it is desirable to examine a number of management options to achieve the best mixture of values gained or lost. The Bureau states that, "This method is the most scientifically and legally defensible one available for most instream flow problems. Further, it best facilitates assessment of impacts resulting from flow alterations and of management alternatives" (U.S. Department of the Interior, 1979).

Three important components of the PHABSIM are field data collection, hydraulic simulation, and the use of electivity curves. In regard to field data collection, the report by Bovee and Milhous (1978) remains the most thorough discussion of appropriate field techniques available in the literature. Sections of this report cover a variety of items, including site selection considerations, data requirements and specifications, surveying techniques, discharge measurements, techniques for large rivers, and equipment lists. No matter which instream flow methodology is being applied, the practitioner should consult this work before heading to the field.

A major task of the CIFSG has been the development of computer software packages to facilitate data handling, hydraulic simulation and computation of weighted usable areas (the output of PHABSIM). The IFG-3 (HABTAT) program is the core of the method. HABTAT utilizes hydraulic input data from either the PSEUDO (Bureau of Reclamation) or the IFG-4 hydraulic simulation programs or direct field measurements and, in conjunction with the electivity curve maintenance program (CRVMNT) containing weighted habitat criteria by species and life stage, computes the weighted usable area (Bovee and Milhous, 1978).

The IFG-4 program is a hydraulic simulation program developed by the CIFSG in 1978 for use with multiple transect methods such as the Incremental Method. Basically, it is a rating curve (stage-discharge) approach, as opposed to PSEUDO which is based on the Manning/Bernoulli equations assuming gradually varied flow. Bovee and Milhous (1978) give the following general description of IFG-4:

"The IFG-4 program utilizes two or more sets of stage and velocity measurements taken at different discharges to establish a least-squares fit of log stage versus log discharge, and log velocity vs. log discharge for each measurement point on the cross section. Input to the program may be taken directly from the field notes. Required inputs are:

1. Water surface elevation at each cross section.

2. Velocities at specified intervals across section.

3. Ground elevation (cross sectional profile).

4. Distance between cross sections.

5. Estimate of substrate composition at each velocity measurement point."

"Given these inputs, the program computes the discharge for each set of calibration measurements. Outputs from the program include:

1. Station indexing.

2. Distance across transect from zero point.

3. Average depth of channel subsection.

4. Average velocity of channel subsection.

5. Substrate of channel subsection."

"These parameters may be obtained for up to 100 channel cross section subdivisions."

"For each discharge simulated at each cross section the program also outputs an 'adjustment factor.' For a given discharge, the depths and velocities across the section are calculated independently. If the predicted depths and velocities are accurate, a discharge calculated from these variables should equal the discharge originally requested. The 'adjustment factor' is a ratio between the discharge calculated from these simulated parameters and the discharge requested. This factor can be used as an indicator of the accuracy of the predictions; the closer to 1.0 the ratio is, the better the predictions. If the adjustment factor deviates significantly from 1.0 ±10% it indicates that some change has occurred on the stage-discharge relationship, and either more measurements are needed, or some manipulation of the data is needed to calibrate the model. This most frequently occurs at low flow extrapolations, and overbank, high flows."

Another major task addressed by the CIFSG has been the development of weighted fish habitat criteria by means of electivity curves for use with the PHABSIM as well as other instream flow methods (see previous section on Oregon Method). Such curves were previously termed "probability-of-use." However, due to the confusion caused by this nomenclature at the Workshop in Instream Flow Habitat Criteria and Modeling, held at Colorado State University in 1978, the term has been changed to "electivity" (Proceedings ed. by Smith, 1979).

To date, the CIFSG has published electivity curves for 10 species of the Family Salmonidae (Bovee, 1978). Since this publication, work has continued on the development of such curves for ∿40 other species and their life history stages (Bovee, personal communication, March 1980). Also the CIFSG has focused attention on the assumption that there is "statistical independence among variables used in describing the preferred instream station (focal point) and spawning requirements comprising the microhabitat conditions" (CIFSG, 1979). This ongoing effort is an outgrowth of the critique by Patten et al. (in Smith (ed.), 1979) at the Colorado State University Workshop.

A variable which currently is not considered in the operational version of PHABSIM is cover. At present, an experimental version of PHABSIM including cover has been developed and is undergoing component testing. The cover equations and their perceived usage will be the subject of an information paper to be published in the near future (CIFSG, 1979).

The CIFSG (1979) has also been involved in the development of a regional or reconnaissance grade methodology for instream flow determinations. To date, most applications of the Incremental Method have been for site specific studies. During the course of their Second National Water Assessment, the Water Resources Council recognized the need for such a regional method (Bayha, 1978). As a result, the CIFSG became involved.

Currently, an unpublished method has been developed based upon Riverine Analysis Areas (RAA's), the representative reach concept, target fish species, simulation modeling techniques, and criteria curves for fish habitat and recreational activities. This method has been undergoing testing and comparison of results with the Incremental Method, and sometime in the near future should be published in report form (CIFSG, 1979).

The CIFSG is also near publication of a "Glossary of Instream Flow Terms."

## Testing and Comparison of Methods

During the past several years, a major emphasis in the instream flow field has been the testing and comparison of the various methods available for use. Generally, the procedure followed has been to select one of each of the several types of methods currently in use (i.e., one of the several non-field types, one of the single transect types, one of the multiple transect types) and apply each of the methods to the same study stream reach under the same general conditions. Evaluation of the methods was then made based upon the time and effort required for each and, most importantly, the reasonableness of the flow recommendation in comparison with the other methodologies, professional judgment, and/or long-term standing crop and related flow data.

The U.S. Fish and Wildlife Service has contracted with 13 of the western states to undertake such evaluation studies. At present, only two of the states (Montana and Colorado) have completed reports on their work. The remainder should be completed in the very near future (Bovee, personal communication, March 1980). Following are summaries of the two completed studies as well as the results of several investigations conducted separately from the current Fish and Wildlife Service endeavor. As the results from all states are not yet published, it would be unfair at this time to draw any final conclusions.

### Montana Evaluation (Nelson, 1980)

In Montana, the following four instream flow methods were applied to five reaches of the Madison, Big Hole, Beaverhead and Gallatin Rivers in the southwest portion of the state:

1. a single transect method, utilizing the IFG-4 hydraulic simulation model, in which the minimum flow recommendation was selected at the inflection point on the wetted perimeter-discharge curve for a single riffle transect;

2. a multiple transect method, using the PSEUDO or Water Surface Profile (WSP) hydraulic simulation model, in which the minimum flow recommended is at the inflection point on the wetted perimeter-discharge curve for a composite of transects, all generally located within a single riffle-pool sequence;

3. the Tennant method, a non-field method based upon historical streamflow records;

4. the CIFSG Incremental Method.

In this test, the recommendations determined by the four methods were compared to those derived from analysis of long-term trout standing crop and flow data. Two minimum flow recommendations were generally provided by the trout-flow data. Flows greater than the most desirable minimum recommendation sustained the highest standing crops, while flows less than the absolute minimum appeared to result in substantial reductions in the standing crops of adult trout or the standing crops of particular groups of adults, such as trophy-size fish. A criterion for evaluation was that the optimum flow recommended should either equal or exceed the most desirable minimum.

Following is a summary of the results and conclusions of the Montana evaluation (from Nelson, 1980):

[1] "The recommendations generated by the single transect method for all five reaches compare favorably to the absolute minimums derived from the trout-flow data. Single, well defined inflection points were generally present and easily interpreted. In addition to providing reliable and consistent recommendations, the single transect method was also the most time and cost efficient of the three field methods."

[2] "The multiple transect method provided acceptable absolute minimum recommendations for the four reaches having discernible inflection points. Inflection points, when present, were generally not as well defined as those on the wetted perimeter curves derived for the single transect method. In the two reaches having more than one inflection point, the lowermost occurred at the flow approximately equal to the absolute minimum recommendation. While the multiple transect method did provide acceptable absolute minimum recommendations for four of the reaches, it had no advantage over the single transect method. It was costlier, more time consuming, sometimes difficult to interpret, and occasionally unproductive."

[3] The results of the evaluation of the Tennant Method are presently being corrected and revised and thus are not available at the time of the writing of this Prologue (Nelson[7], personal communication, February 1980).

[4] "The acceptance of less than 50% of the optimum flow recommendations indicates that the IFG incremental method in its present state of development is not a consistent method for deriving instream flow recommendations for the trout rivers of Montana. Possible means for improving the present IFG method for use on the relatively high gradient, boulder and cobble-strewn trout rivers of the study area include (1) modifying the existing IFG model to use bottom velocities rather than the mean velocities in the water column to compute the weighted usable area, (2) developing probability-of-use curves from data collected for river populations of trout, and (3) incorporating cover into the IFG model."

[5] "The predictive capabilities of the IFG-4 and the Water Surface Profile (WSP) hydraulic simulation models were also evaluated. The IFG-4 predictions of water surface elevations, velocity and depth were generally superior to those of the WSP model. The IFG-4 predictions of wetted perimeter, even though approximations, were judged superior to those of the WSP model based on the greater accuracy of the predictions of water surface elevation. Additional testing is needed to clarify the reliability of the wetted perimeter predictions of both models."

Colorado Evaluation (Prewitt and Carlson, 1977)

During the course of this evaluation study, four instream flow methods were applied to various reaches of the middle Yampa and White Rivers, large streams located in the upper Colorado River basin of northern Colorado. These methods were:

1. the Tennant method;

2. a single transect method utilizing the R-2 Cross computer program for hydraulic simulation;

3. a multiple transect method utilizing the WSP computer program for hydraulic simulation,

4. the CIFSG Incremental method.

The resultant flow recommendations were evaluated against the weighted usable area predictions derived from the CIFSG Incremental method and also against actual field observations of physical and biotic conditions in both rivers.

The following conclusions were reaches by the investigators (from Prewitt and Carlson, 1977):

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[7]Montana Department of Fish, Wildlife and Parks, Bozeman, Montana 59715.

Fixed-Percent Methodology:

"1. The Tennant method must be used with a thorough understanding of the flow regime of the river in question. Specific monthly-mean flow printouts are very helpful in determining the validity of Tennant-method recommendations, as are correlations with physical, chemical and biotic conditions at the prescribed flows when they are available from other sampling studies. If the 30 percent flow is less than the monthly flow not exceeded one in every two years, it may be too low to request as a flow which will become a permanent low-flow after dams and diversions are in operation...."

"2. Effort should be made to account for waters lost to consumptive use and not shown in gage data. Fixed-percentage methodologies are more accurate when applied to mountain streams or protected rivers which exhibit essentially virgin flow. For such rivers as those in the Upper Colorado River Basin, application of the Tennant method is weakened by uncertainties in recreating a mean annual flow by additions of poorly-known quantities lost to agricultural and municipal use and transmountain diversion.

If cost and time limit or prohibit field studies, flow recommendations by Tennant method procedures are acceptable only if proper consideration is given to the available hydrologic and biotic knowledge of the river."

Single Cross-Section Methodologies:

"1. Placement of the cross-section is critical to reproducibility of flow recommendations using any presently-available single-cross section methodology...."

"2. Application of fixed criteria (such as percent wetted perimeter, minimum velocity, etc.) to single cross-section computer output often results in flow recommendations which fail to incorporate the unique needs of certain species or their life history stages...."

"3. Field procedures used in gathering single cross-section data may have a significant effect upon the reliability of the hydraulic model. We suggest that, on rivers greater than 30 m in width, a surveying instrument be used instead of an Abney level or a clinometer to match elevations of the tape ends and to determine water surface slope. Also, alternate flows should be observed if at all possible, even if only one additional flow is available to establish a rating curve."

"4. A modified version of the R-2 Cross program which requires fewer input steps and provides output more directly applicable to instream flow situations is available from the IFG in Fort Collins, Colorado [IFG-1]."

Multiple Cross-Section Computer Methodologies:

"1. Multiple cross-section methodologies provide a more flexible tool for use with species-response criteria than do single cross-section methodologies...."

"2. Output from the original WSP ('Pseudo') program was of limited utility to instream flow users...."

"3. Percent wetted perimeter and lowest inflection points on the graphs of area, velocity or wetted perimeter vs. discharge probably have little relevance to the unique fauna of the Upper Colorado River Basin...."

"4. On large rivers in the Upper Colorado River Basin, the following technical and analytic problems may arise: 1) Measurement of water surface elevations. Water surface slopes are usually about .001 on rivers similar to the White and Yampa Rivers. If studied reach lengths are too short and water surface elevations carelessly measured, errors may result which would prohibit calibration of the model. 2) Typically, long reach lengths are required on these rivers to adequately describe a given habitat unit. When such conditions exist, the following procedure is helpful in obtaining reliable surveying results efficiently: a) Close the level loop first, immediately after site selection and driving of headstakes. b) Determine water surface elevations at all cross-sections. If manpower permits, determine discharge and verification velocities at this time or immediately afterward. c) Obtain cross-sectional data as time permits. Cross-sections with at least 15 coordinate pairs will provide better resolution if the data are to be used in more detailed methodologies such as the IFG incremental flow methodology. Also, on large, arid rivers, more detailed measurements often disclose the presence of small, flat or depressed areas which provide backwater nursery grounds for cyprinid and catostomid larvae and must be considered in rearing flow recommendations. d) Measure distances between cross-sections at the water line, grass line and along the thalweg line, if possible. Future refinements in existing programs may allow use of such dimensional data to construct plan-view topographic maps of the study reach. Again, verification of hydraulic models by observation of at least two disparate discharges is highly desirable."

Multiple Cross-Section with Output Manipulation (CIFSG Incremental Method):

"1. Use of multiple cross-sectional data in the [HABTAT] program provided the most comprehensive analytic and predictive tool for use in flow recommendations on rivers such as the Yampa and White Rivers...."

Cost and Time Evaluations:

"1. Because of the various applications and adaptations of each methodology by different users, direct cost comparisons were not possible. The level of efficiency attained by individual users probably varied enough to prevent accurate cost comparisons between two agencies using precisely the same methodology. The cost and time comparisons were thus made on a general basis, as they pertained to the procedures followed in this study."

"2. The Tennant method offers high time-cost benefits,..."

"3. Sag-tape field measurements (R-2 Cross) are relatively quick (two sites per day are possible if long inter-site travel is not required), but a three-man crew is ideal (if not absolutely necessary), and equipment may be more expensive than that required to do multiple cross-section procedures because of the need for a calibrated steel tape and tension handle, as well as surveying equipment. Single cross-section measurement procedures done strictly with surveying equipment are quicker and less expensive."

"4. As the use of surveying equipment is necessary to assure accuracy even of sag-tape procedures, we feel that at least three cross-sections could be surveyed by an experienced crew in only slightly more time (about 4 hr for very long study sites) than the same crew could perform a single sag-tape procedure. The increased analytic capability gained thereby (from use of the WSP, S-D [IFG-4] or Habitat [HABTAT] programs) would more than outweigh the small additional time deficit. Also, the extreme dependence upon proper placement of a single cross-section is somewhat relieved when a larger habitat unit is described by multiple cross-sections. Equipment costs, allowing $750.00 to $1,000.00 for the surveying instrument, pole and tripod, may be as much as $300.00 less than those for sag-tape procedures because no steel tape or tension handle are needed...."

Upper Little Snake River Drainage, Wyoming Comparison (Wesche et al., 1977, and Jespersen, 1979)

As previously noted, Wesche et al., and Jespersen applied very similar modifications of the USFS Region 2 method to the same stream reaches of the same study streams in the upper Little Snake River drainage of southeastern Wyoming. Working independently and several years apart, the resulting recommendations were exceptionally close, as shown in Table P-5. These results would tend to indicate "reproducibility," a necessary attribute of any instream flow method.

Central Utah Evaluation (Rose and Johnson, unpublished draft)

The Central Utah evaluation was conducted by personnel of the U.S. Fish and Wildlife Service (USFWS) and Bureau of Reclamation on the Strawberry River, a trout stream designated as blue-ribbon by the Utah State Division of Wildlife Resources. It should be noted that this study was not undertaken by the USFWS under the current evaluation program ongoing in 13 western states, but was a forerunner of it. Methods tested included:

1. the R-2 Cross method (Critical Area method) as applied by the Colorado Division of Wildlife (termed the "Modified Sag Tape method" by the authors);

2. the Tennant method;

3. a multiple transect method quite similar to the USFS Region 4 method, but without hydraulic simulation capability (termed the "Forest Service method" by the authors).

The recommended flows in cubic feet per second derived from the three methods were as follows:

| | Maintenance Flow | Optimum Flow |
|---|---|---|
| Method #1 | 12 | 22 |
| Method #2 | 9 | 19 |
| Method #3 | 12 | 25 |

As shown, the results of the three methods were quite close. However, the time required to derive these recommendations varied greatly: Method #1, 435 man-hours; Method #2,

Table P-5. Comparison of instream flow recommendations by Wesche et al., (1977) and Jespersen (1979).

| Stream | Instream Flow Recommendation* (cfs) | |
|---|---|---|
| | Wesche et al. | Jespersen |
| Harrison Creek | 1.0 | 0.75 |
| Solomon Creek | 1.0 | 1.0 |
| Deadman Creek | 2.0 | 2.0 |
| West Branch of the North Fork of the Little Snake | 3.5 | 3.5 |
| Roaring Fork of the Little Snake | 0.75 | 1.0 |

*Recommendations stated as "'x' cubic feet per second or the natural flow, whichever is less."

0.5 man-hours; Method #3, 2,880 man-hours. These man-hour figures are presented here only to give a rough approximation of the relative differences between methods and certainly should not be used for planning future studies.

The tentative conclusions reaches by Rose and Johnson (1976) were as follows:

"1. The method used by the Bureau of Reclamation's study team, while effective, is much too expensive and time consuming for widespread practical application."

"2. The 'Montana method' is an effective method for determining instream flow requirements. It is quick, easy, and has a very broad application."

"3. The 'modified sag-tape method' is an equally effective method for determining instream flow requirements. It, too, is quick, easy, and has an even broader application than the 'Montana method' in that it may be used on streams where flow records are not available. It also has the advantage of computer analysis facilitating physical data for the actual streamflow at the time of measurement, as well as for ten or more selected water stages; and visual representation of the stream profile at each selected level."

## Related Research

Since the initial writing of the Research Needs chapter of this report in 1976, a number of research activities have been undertaken to fill the data gaps identified. Certain of these projects have been completed while others are still ongoing. The intent here is to alert the reader of these research activities and to assist in establishing lines of communication between the practitioner involved in the instream flow field and the researcher. Following are selected research summaries grouped by general research area.

### Carrying Capacity Concept

A number of researchers have been actively engaged in studies of the relationship between fish habitat and the standing crops of fish which can be supported by that habitat. Binns[8] (1976) and Binns and Eiserman (1979) developed a habitat quality index (HQI) rating system based upon ten attributes best related to trout standing crop. The habitat attributes selected for use in the HQI system were critical period stream flows, annual stream flow variation, maximum summer stream temperature, water velocity, cover, stream width, food abundance, food diversity, nitrates and stream bank stability. A relatively high correlation (R = 0.95) was then found between HQI scores and trout standing crops at 20 study sites on a wide variety of Wyoming streams.

[8]Dr. Allen Binns, Wyoming Game and Fish Department, Lander, Wyoming 82520.

Corman[9] and Karr[10] (1978) in a study of streams in Panama and Indiana, defined four variables as being the most important in determining the distribution and abundance of stream fishes: (1) habitat structure, (2) flow regime, (3) energy source, and (4) water quality.

The CIFSG (1979) has been involved in testing of the relationship of the PHABSIM model output (weighted usable area) to trout standing crop data from 20 brown trout stream reaches and 22 brook trout stream reaches in southeast Wyoming. Trout data for the test were provided by Thomas A. Wesche, Wyoming Water Resources Research Institute, University of Wyoming, Laramie. For adult brook trout, a correlation coefficient of 0.77 was observed between biomass and weighted usable area when temperature was introduced as a variable. Linear univariate correlations of adult brown trout populations and biomass estimates against weighted usable area resulted in correlation coefficients of 0.84 and 0.90, respectively.

Wesche, using the trout data mentioned above, is currently completing a study of the relationship between trout cover ratings (Wesche, 1973, 1974) and trout standing crops. This work has been funded by the Wyoming Game and Fish Department and the Office of Water Research and Technology (USDI). The results should be available by mid-1980.

Since 1973, the Oregon Department of Fish and Wildlife[11] has been conducting research on salmonids attempting to develop techniques that can be used to estimate the effect of stream flow on fish production. A major thrust of this effort has been directed toward the development of a model for predicting salmonid standing crop from measurements of stream habitat. Nickelson (1976) and Nickelson and Hafele (1978) present the results of these studies to date.

The University of Idaho's Fishery Resources Department[12] has been very active in this research area also, with funding from the Office of Water Research and Technology through the Idaho Water Resources Research Institute. A study entitled, "The Effects of Reduced Stream Discharge on Fish and Aquatic Macroinvertebrate Populations," is scheduled for completion April 30, 1980. A second three-year study, "Development and Validation of Habitat-Standing Crop Functions for Select Stream Fish and Fish Food Organisms," is beginning in March 1980 (White, personal communication, February 1980). Dr. Robert White is the Principal Investigator for both research efforts.

Habitat Criteria

The area of habitat criteria research is so large and diverse it would be impossible to even briefly summarize here. Let it suffice to say that the CIFSG has become a center for the accumulation of such data. As previously stated, the Group has already developed electivity curves for approximately 50 fish species.

Several related studies of particular interest in the Rocky Mountain area are provided below.

Winter Trout Microhabitat. A study of brown trout winter microhabitat using radio telemetry techniques was conducted by Wichers and Wesche (1980, in press) at the Wyoming Water Resources Research Institute (WRRI) with funding provided by the Office of Water Research and Technology, the Wyoming Game and Fish Department, the Wyoming Water Planning Program, and the University of Wyoming. A Water Resources Series publication detailing the results of this work will be available by mid-1980. A continuation of this study is currently being conducted by WRRI (James Gore[13], Principal Investigator) using radioisotope tracers.

Macroinvertebrate Microhabitat. As mentioned above, macroinvertebrate microhabitat studies are now ongoing at the University of Idaho. Research in this area is also underway at Wyoming WRRI (Gore, Principal Investigator) in cooperation with CIFSG.

Salmonid Egg Incubation. A study entitled, "Development and Application of a Methodology for Recommending Salmonid Egg Incubation Flows," is currently nearing

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completion at the Fishery Resource Department, University of Idaho (Principal Investigators Dr. Robert White and Dudley Reiser, Ph.D. candidate). While the primary objective of this research is to develop a methodology for recommending salmonid incubation flows, the effects of dewatering and low flow on the egg environment, egg survival and fry quality are also being assessed.

Hydraulic Simulation Technique

The work of Silvey in regard to prediction of Manning's n values at stimulated water stages has been previously discussed. Hill (1978), through the analysis of roughness coefficients for mountain streams in southeast Wyoming and northcentral Colorado, developed a procedure utilizing a branching tree diagram in combination with water surface slope and observable characteristics to aid field personnel in the evaluation of n values. While the procedure is relatively untested, it may have merit in the instream flow field.

As previously discussed, the CIFSG has been intensively involved in research activities dealing with hydraulic simulation techniques. The CIFSG (1979) reports that further testing of the predictive capabilities of PHABSIM is now underway with two field tests being run in association with the U.S. Geological Survey and the Corps of Engineers.

## PREFACE

The attainment of a satisfactory solution to any problem dictates that an orderly procedure be followed. Outlined in Figure 1 is the general approach, by task, the forest manager and planner should follow in determining the amounts of water needed instream to maintain resource values. The objectives of this schematic presentation are to:

1. Provide an overview of the tasks necessary in confronting and finding solutions for instream flow problems.

2. Direct the manager to that portion of this handbook which is responsive to and offers guidance for the completion of each task.

3. Point out for which tasks direct input is required from the Forest Service inter-

GENERAL APPROACH TO DETERMINE INSTREAM FLOW NEEDS

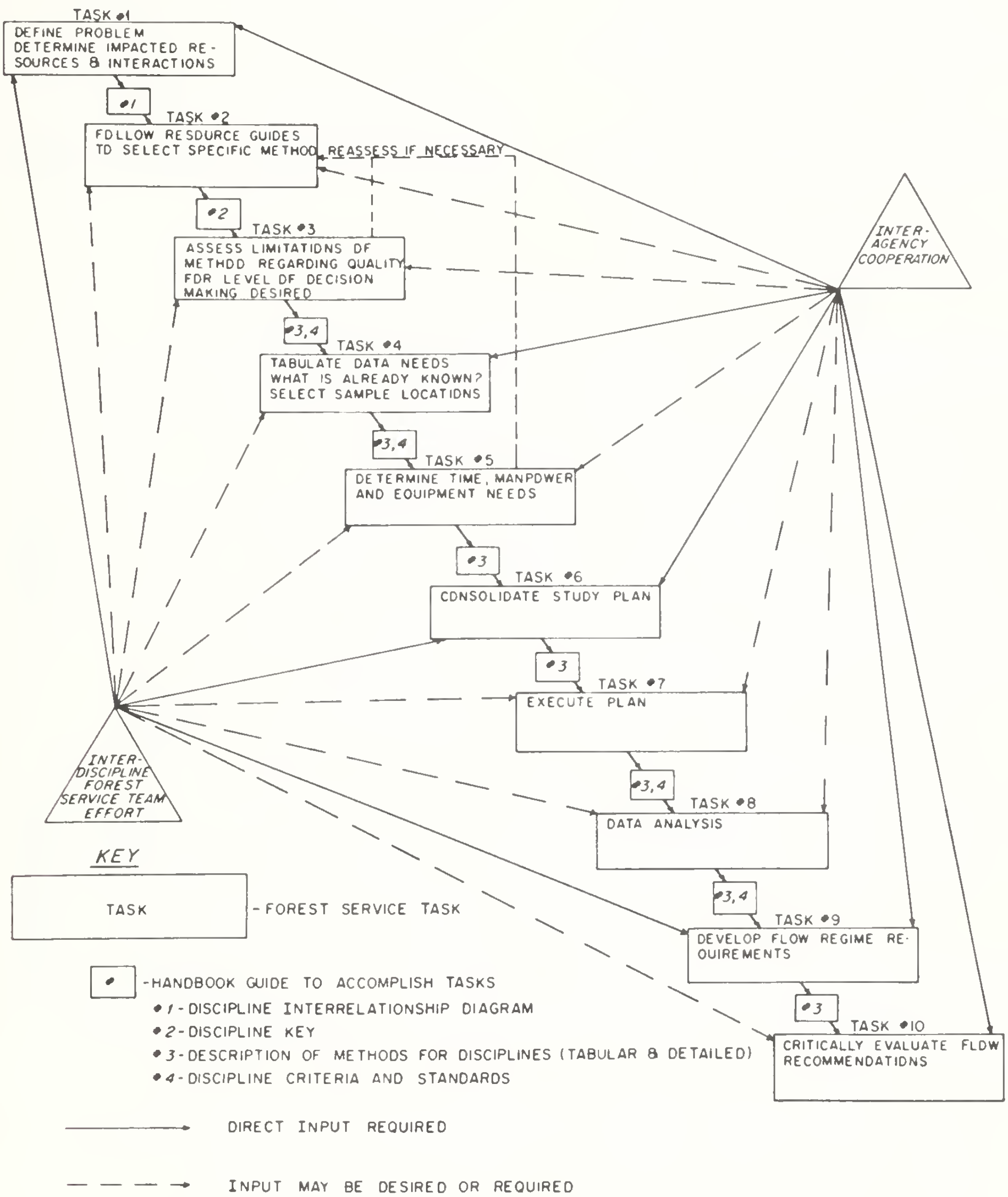



Figure 1. General approach to determine instream flow needs (IFN).

disciplinary team (normally composed of a hydrologist, a terrestrial and/or aquatic biologist, and a landscape architect) and from other agencies and organizations (federal, state and/or private).

The forest manager and planner dealing with the allocation of streamflows will seldom be involved in a situation where only one instream value or resource is in question. Instream flow problems are inherently multi-disciplinary. Given an altered streamflow regime, Figure 2 attempts to illustrate the interrelationships and interactions which may occur among the disciplines. Careful study of this diagram should assist the reader in the completion of Task #1, determining which resources may be impacted, given the particular set of circumstances with which he is working.

The objective of this document is to provide the reader with a detailed summary and critique of available methods for estimating and recommending suitable instream flows necessary to optimize or maintain habitat for fishery resources. The material presented herein represents a portion of a more comprehensive, inter-disciplinary, three-volume report prepared for the Forest Service by the University of Wyoming Water Resources Research Institute under Cooperative Agreement 16-556-CA entitled, "Determining Instream Flows for Management of Aquatic and Riparian Ecosystems."

The authors wish to express their sincere thanks to the many people of the Forest Service and the University of Wyoming who have in one way or another assisted in the preparation of this document.

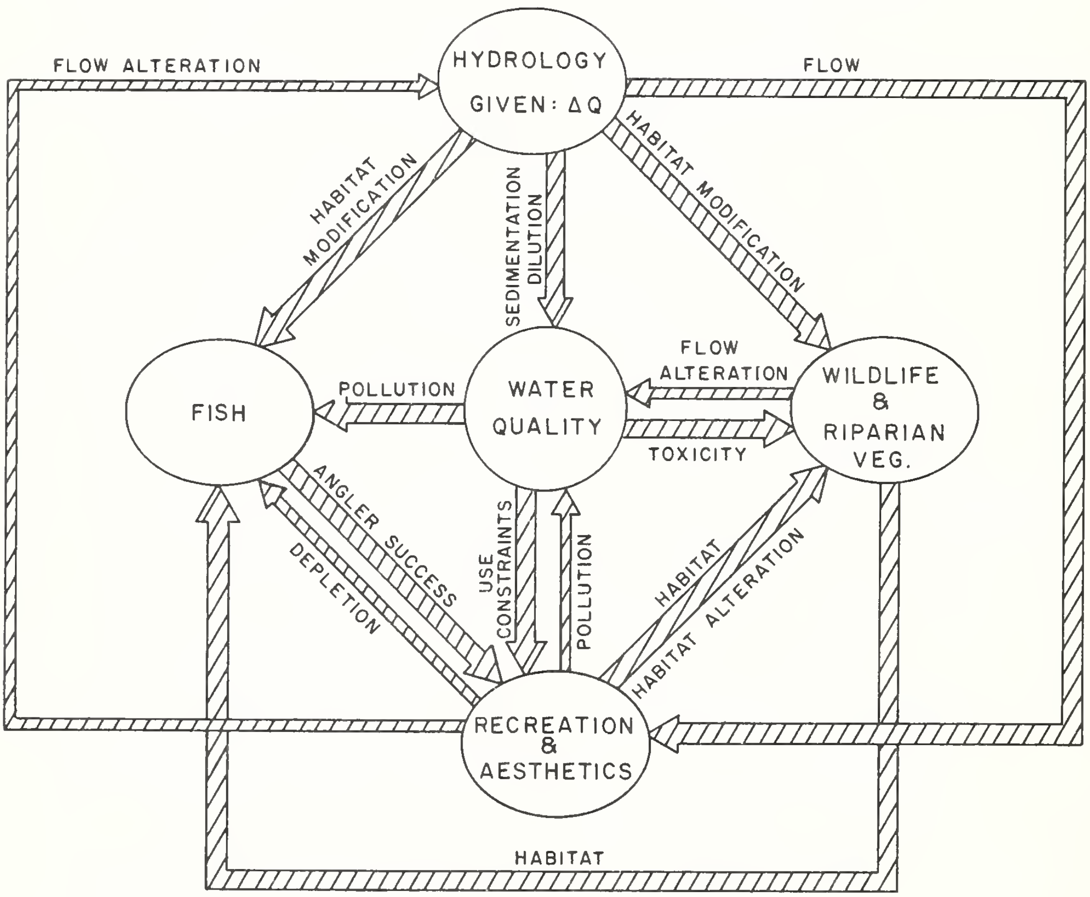



Figure 2. Disciplinary interrelationships and interactions.

## INTRODUCTION

Methodologies for estimating suitable instream flows necessary to optimize or maintain habitat for fishery resources are numerous. Both federal and state agencies, as well as private concerns, have become involved over the past several years in this development and application process. From these efforts, methodologies have evolved along two lines, one based upon the manipulation, synthesis and interpretation of streamflow records, the other based on the collection of field hydraulic data and the subsequent application of available fish habitat criteria to determine flow-habitat relationships. Generally speaking, the former methodologies require low time and financial inputs, while the latter yield a flow recommendation of higher resolution, one tied at least partially to the biological needs of the fish population involved.

Presented in Figure 3 is a Key to Fisheries Instream Flow Methodologies which we feel may have application to streams in Regions 2 and 3. The purpose of this Key is to guide both the manager and the administrator in the selection of the methodology best suited to their project scope, the physical constraints placed upon them in terms of available time, money and manpower, and the output desired through the methodology application process. As with any key, the overriding purpose is to induce the investigator to make necessary decisions. Through this process, it is our intent to present the various options available, with the present state of knowledge, for given sets of input conditions.

Once a methodology is selected from the Key, the reader should next review the summary of that method (see SUMMARY OF METHODOLOGIES) to make certain it will fit his needs. From here, the detailed description of the method should be consulted (PROCEDURES). The final section (RESEARCH NEEDS) lists and discusses pertinent research areas which need to be explored to broaden our knowledge of the effects of streamflow manipulation on aquatic organisms and to increase the reliability and effectiveness of the methodologies described herein. Appendix A presents in tabular form life history information for a variety of fish species as well as habitat criteria (water depth, water velocity and substrate) for their life functions. The reader will find these criteria of use in conducting certain of the field methodologies described. The concluding section of this report (Appendix B) contains a formal summary of literature describing the importance of the various habitat components necessary to sustain salmonid populations in a lotic environment.

Before proceeding to the Key and description of methods, the reader is urged to carefully inspect the COOPERATIVE INSTREAM FLOW SERVICE GROUP section describing the work of the Cooperative Instream Flow Group and the Incremental Method they have recently developed and to first review the following guidelines and recommendations which are offered to assist in the methodology selection process:

1. When possible, field methodology should always be preferred over strictly office methods. Courtroom testimony based upon observations and measurements at the site should carry more weight than purely "dry-lab" techniques.

2. Before committing time to the application of any methodology, carefully assess the output required (i.e., the type of recommendation desired) in light of the input resources available (time, manpower, money, discharge records, fisheries habitat criteria, etc.). The Key should be of assistance in this process.

3. Of the available office methodologies, the most intensive is the flow duration curve method developed for the Northern Great Plains Resource Program (NGPRP). This method is applicable to streams of all sizes and types of fisheries for which discharge records are available. While this method does not make specific recommendations for the various fish life-history stages, it does make one general, and quite reasonable, assumption that the aquatic biological resource present is a function of past discharges. The outputs of the method are monthly flow recommendations which, although based entirely on hydrology, do serve to provide the fishery with a somewhat natural flow regimen. While these flow recommendations may often appear to be quite low, they are based on discharges normally available. Care should be taken when applying the NGPRP method that temperature and dissolved oxygen problems do not develop. This is especially important in lowland situations.

4. As shown in the Key, numerous IFN field methods have been developed for assessing and analyzing habitat-flow relationships. Inspection of these methodologies indicates that, while they have been developed in various geographic locations for various species of fish and differ in the intensity of field effort required, the basic data collection tool, the cross-channel transect, is the same. Differences occur in the number of transects run, the number of flow levels investigated, the selection process of the transect location and the species habitat criteria applied to the data. Our review of the documents describing these methodologies has led us to the

KEY TO FISHERIES IFN METHODOLOGIES

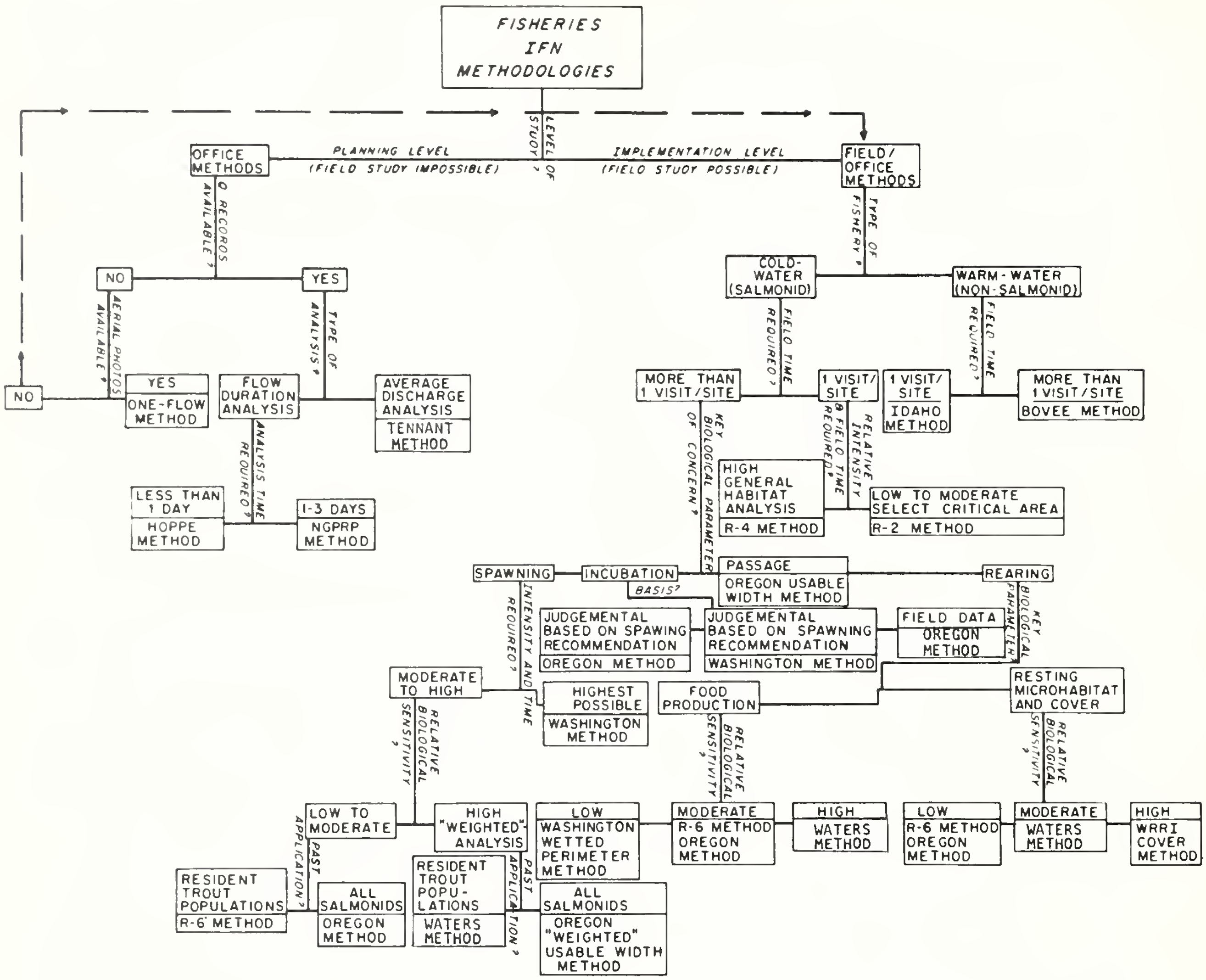



Figure 3. Key to fisheries IFN methodologies.

conclusion that, overall, considering both the input required and the output obtained, the most comprehensive methodology currently available is the Incremental Method recently developed by the Cooperative Instream Flow Service Group (see COOPERATIVE INSTREAM FLOW SERVICE GROUP). While this method is new and relatively untried, it conceptually draws its basis from several of the established, often applied, methodologies. "The method is designed to accommodate numerous fish species and life history stages. It outputs equivalents of optimum habitat expressed in surface area of the stream reached modeled for each flow of interest. By knowing the periodicity of each species' life history, the investigator can describe the amount of habitat available each month for each life stage under any flow frequency of interest. The fishery manager can use this information to compare available habitat for species and life stages at many unobserved flows" (U.S. Department of the Interior, 1977). Field work for this method may require several visits to the study stream and a crew of 2 to 5 people. Computer programs are available to handle the hydraulic simulations and the development of flow versus usable habitat plots, thus greatly reducing field and office time. Equipment needs are no greater than for most other field methodologies. Also, as the Instream Flow Group is a "service" group, its staff is most eager to assist practitioners of the method.

5. When dealing with smaller brown trout streams (average discharges of 100 cfs or less), it is recommended that added importance be given to bankside cover and instream resting microhabitat. The methodology developed by Wesche (1973 and 1974) is suitable for this, especially because it is one of the few methods available at present which has at least begun to define the habitat-population relationship. In the past, field measurements have been necessary at several flow levels. However, as this method is based upon transect data and water depths along bankside cover in close association with the transects, field time can be reduced tremendously by collecting these data with the sag-tape or tight-tape technique and by synthesizing trout cover ratings at additional flow levels using the R-2 Cross or WSP program.

6. Regardless of the methodology being applied, all transect data should be collected using a technique such as sag- or tight-tape. This will add "computer capability potential" to all such data, even if this is not immediately needed.

7. When making an instream flow recommendation, be certain to very carefully define the stream reach the recommendation is for. Use township, range and section numbers as well as other pertinent descriptors.

8. State your recommendation in terms of the lowest <u>instantaneous</u> flow permissible (i.e., "at no instant in time should flow be less than X cfs"). This will preclude the problem of vast daily flow fluctuations below a control structure, which for a given day, may average out to be the recommended flow, but at times during that day may be as low as zero.

9. Regardless of the methodology used, do not make your recommendation "in a vacuum." If a stream is of little or no fishery value, don't base your recommendations on fishery considerations. Possibly water quality, recreation or aesthetics would serve as a stronger base. Also, for any recommendation, use an interdisciplinary approach if at all possible. The greater and more varied the input, the stronger and more defensible will be your output.

10. The Cooperative Instream Flow Service Group recommends formulating instream flow recommendations for average and dry year conditions so that in negotiations the required flow can fluctuate with the supply allowing for the fishery to take advantage of good water years.

## COOPERATIVE INSTREAM FLOW SERVICE GROUP

### Background

The Cooperative Instream Flow Service Group (IFG)[1] was formed in July, 1976, under the sponsorship of the U.S. Fish and Wildlife Service with funding provided by the U.S. Environmental Protection Agency and the Water Resources Council. While IFG is organizationally linked to the U.S. Fish and Wildlife Service as part of the Western Water Allocation Project, Office of Biological Services, it is an interdisciplinary group. Members of the group include details from a variety of federal and state agencies serving under the Inter-Governmental Personnel Act whose expertise lies primarily in the areas of aquatic ecology, hydrology, recreation, and legal and institutional affairs (U.S. Department of the Interior, 1977).

### Goal

The goal sought through the formation of the IFG was "to establish an entity which could utilize the contributions of different agencies and persons from different disciplines to advance the state-of-the-art and become the center of activity related to instream flow assessments" (U.S. Department of the Interior, 1977). The IFG was specifically established to address and to interrelate the following four major components of instream flow activities:

1. Physical: to gain a basic understanding of possible changes in stream channel morphology and hydraulics resulting from altered flows.

2 and 3. Biological and Recreational: to develop improved methods to predict the effects changes in channel configuration, flow regime and other hydraulic factors will have upon aquatic life and recreation uses.

4. Decision-Making: to develop an awareness of management and operation processes and legal and institutional constraints.

### Accomplishments

In the areas of fisheries biology and aquatic ecology, the major accomplishments to date include:

[1]Cooperative Instream Flow Service Group, Creekside Building, 2625 Redwing Road, Fort Collins, Colorado 80526, phone (303)223-4275, FTS 323-5231.

1. The development of the Incremental Methodology for analysis of alterations in streamflow and channel characteristics. This method will be discussed in detail in the following section of this chapter.

2. The development of species criteria in the form of Suitability Index Curves for fish species. Vital data requirements for most instream flow studies are the habitat criteria (defined in terms of water depth, velocity and substrate) for the species and life history stages involved. The IFG, through an extensive search of the literature, has developed such criteria for 45 fish species. For each species, curves have been drawn identifying the range and preference of each life history stage (including spawning, incubation, fry, juvenile, adult and passage) for the hydraulic parameters of depth and velocity, as well as substrate and temperature. The criteria are based on the assumption that individuals of a species will tend to select the most favorable conditions but will also utilize less favorable conditions, with the probability of use decreasing as conditions approach the end points of the range. Currently, the following two publications are available from the IFG regarding this work:

a. Bovee, Ken D. and Tim Cochnauer, 1977. Development and evaluation of weighted criteria, probability-of-use curves for instream flow assessment: Fisheries. Instream Flow Information Paper No. 3. FWS/OBS-77/63. 39p.

b. Bovee, Ken D. 1978. Probability-of-use criteria for the family Salmonidae. Instream Flow Information Paper No. 4. FWS/OBS-78/07. 80p.

3. The development of Hydrology/Hydraulics Prediction Models. The objectives of this phase of the IFG program have been to: (1) determine the depth-velocity-substrate distribution of flow in a stream channel; (2) determine the monthly flow pattern and the frequency distribution of flows; (3) determine the impact of modifications in water or sediment discharge on the depth-velocity-substrate distribution of the reach; and (4) develop methodologies for collecting hydraulic data on large rivers for instream flow analyses. To date, the IFG has released one publication dealing with this facet of their work:

Bovee, Ken D. and Robert Milhous, 1978. Hydraulic simulation in instream flow studies: Theory and techniques. Instream Flow Information Paper No. 5. FWS/OBS-78/33. 130p.

## The Incremental Method

The Incremental Method, developed by the IFG, allows quantification of the amount of potential habitat available for a species and life history phase, in a given reach of stream, under different streamflow regimes with various channel slopes and configurations. While the method was designed to help formulate instream flow recommendations, it can also be used in assessing the effects of altered streamflow regimes due to proposed water development projects, habitat improvement projects, mitigation proposals, proposed fish stocking programs and negotiating releases from existing storage projects (Bovee, 1978).

In concept, the Incremental Method is a synthesis of portions of various methodologies described in this document. The four main components of the method are:

1. Simulation of the stream (similar to the Region 2 or "Colorado" Method described by Russell and Mulvaney, 1973; Silvey, 1976; and Kochman, 1976, personal communication).

2. Determination of depths, velocities, substrates, and cover objects, by area (similar to the Washington Method described by Collings, 1972 and 1974).

3. Determination of composite probability of use for each combination of depth, velocity, substrate, and cover found within the study reach for each species and life history phase under investigation (similar to the "weighting" factors used by Waters, 1976a; and the "preference" factors used by Wesche, 1973 and 1974).

4. Calculation of a "weighted usable area" (defined by Bovee, 1978, as "roughly a habitat's carrying capacity based on physical conditions alone") for each discharge, species and life history phase under investigation, thereby allowing the development of flow versus habitat plots.

In concept, then, the Incremental Method makes use of portions of other methodologies. However, this should not be construed as "plagiarism" in any sense of the word, but rather as a maturing and refining of the state-of-the-art. There has long been a need for standardization of methods between instream flow practitioners, as well as a more determined effort for assessing not only the physical changes which occur when streamflows are altered, but also the potential biological ramifications (see RESEARCH NEEDS). This the IFG is attempting to do through the development of the Incremental Method and the associated species criteria curves and the refinement of hydraulic simulation techniques.

Stream Reach Simulation. Several hydraulic simulation techniques, with varying input data requirements and levels of accuracy, are routinely used in assessment of instream flow requirements. However, the family of hydraulic simulations most promising in the assessment of channel manipulation is generally termed "backwater curve" calculation.

Several computer programs are available, which can predict the hydraulic parameters of depth, velocity, width, and stage for different discharges. The version utilized by the Bureau of Reclamation (Anonymous, 1968) is termed "Pseudo," while the Corps of Engineers (Anonymous, 1976) has a series of backwater curve programs titled "HEC."

Regardless of the title, all backwater curve or "water surface profile" calculations utilize Manning's equation,

$$Q = N^{-1}R^{2/3}S^{1/2}A,$$

where

$Q$ = discharge ($m^3/s$);

$R$ = hydraulic radius (m), or cross-sectional area divided by the wetted perimeter of the stream (roughly equivalent to mean depth);

$S$ = energy gradient, assumed parallel to slope of the water surface;

$A$ = cross-sectional area ($m^2$);

$N$ = roughness coefficient, which may be calculated from stream measurements, or estimated from a description of bed materials, channel uniformity, and channel shape.

Since $Q = VA$, Manning's equation may be restated as

$$V = N^{-1}R^{2/3}S^{1/2},$$

where

$V$ = mean velocity (m/s).

The stream reach simulation utilized by IFG uses several cross-sectional transects, each of which is subdivided into 9 to 20 subsections. The computer program then treats each subsection as an essentially separate channel. For any stage (water surface

elevation), the mean depth and velocity of each subsection may then be calculated.

An area represented by these values of depth and velocity is calculated by multiplying the width of the subsection by half the distance to the next transect upstream and the next downstream.

The output of the stream reach simulation is in the form of a multidimensional matrix showing the surface area of stream having different combinations of hydraulic parameters (i.e., depth, velocity, substrate, and cover when applicable).

In order to evaluate the magnitude of impacts caused by changes in stream hydraulics, it is necessary to develop an information base for each species or group of species of interest. Such an information base is termed biological criteria.

Biological criteria are primarily aimed at those parameters affecting fish distribution which are most directly related to streamflow and channel morphology: depth, velocity, temperature, and substrate. Cover, a habitat parameter of paramount importance to many species, is also indirectly related to streamflow. Cover may be incorporated into an assessment by evaluating the usability of available cover objects in reference to the flow parameters around them.

Species for which biological criteria are being developed are roughly divided into five classes.

1. Management-objective species are sport and game fishes considered important and desirable by the public, and of imporance to the objectives of the state management agencies.

2. Indicator species are those with narrow habitat tolerances, which inhabit areas of streams which are particularly sensitive to changes in flow. It is assumed that if conditions are suitable for the indicator species, all other species will also have suitable habitat.

3. Rare and endangered species are those which may be locally abundant, but with a highly restricted distribution, or those which occupy much of their former distribution, but in greatly reduced numbers.

4. Important non-game species are those which may act in direct competition with game or sport species.

5. Forage species are organisms occupying intermediate positions in the food chain, including both forage fish and aquatic invertebrates.

The criteria with which this method is concerned are termed probability criteria. The assumption is that the distribution and abundance of any species are not primarily influenced by any single parameter of stream flow, but related by varying degrees to all streamflow parameters. Furthermore, it is assumed that individuals of a species will tend to select the most favorable conditions in a stream but will also use less favorable conditions, with a lower probability of use as conditions become less favorable.

Given a sufficient number of observations and measurements, it is possible to determine a species' preferences within a certain parameter, such as depth. Based on this information, it is also possible to calculate the relative probability that the species will utilize some positive or negative increment of that parameter which falls outside of its preferred range.

Most flow assessment methodologies in current use address only one, or occasionally two, life history stages. Frequently, a particular life history stage or a certain time period is singled out as being critical for the continued well-being of a fish population. For example, spawning success is commonly considered a critical factor in the maintenance of a fish population, but habitat evaluations for fry and juvenile fish are almost universally neglected. However, under the incremental method, probability criteria are developed for all life stages (Bovee and Cochnauer, 1977).

Probability of Use. The composite use probability of any combination of hydraulic conditions encountered in the study reach may be determined from the individual probability-of-use curves for each species and life stage.

For a given increment of each parameter the use probability is read directly from the curve. For example, for adult smallmouth bass the use probability for the depth increment of 105 cm is 0.37. The use probability for the velocity increment of 15 cm/s is 0.81. The composite use probability for adult smallmouth bass for a depth of 105 cm and a velocity of 15 cm/s is 0.37 x 0.81 = 0.30. A composite probability is similarly calculated for each stream reach subsection.

Substrate or cover may also be incorporated into this determination of composite probability following the procedure detailed above. In the preceding example, if the substrate found with that combination of depth and velocity had a probability of use of 0.90, then the composite probability of use for that combination of depth, velocity, and substrate would be 0.37 x 0.81 x 0.90 = 0.27.

Weighted Usable Area. The weighted usable area is defined as the total surface area having a certain combination of hydraulic conditions, multiplied by the composite probability of use for that combination of conditions. This calculation is applied to each cell within the multidimensional matrix.

This procedure roughly equates an area of marginal habitat to an equivalent area of optimal habitat. For example, if 305 $m^2$ of surface area had the aforementioned combination of depth, velocity, and substrate it would have the approximate habitat value of only 82.4 $m^2$ of optimum habitat.

For each species and life stage, weighted usable area is plotted against various monthly flow regimes, such as median monthly flows or 1-in-10 year monthly low flows. Such plots can show critical time periods for a given life stage, the limiting habitat availability for each life stage (i.e., physical carrying capacity), and the limiting habitat availability for different species. Since changes in hydraulic characteristics will initiate differential species reactions, the method is particularly useful in predicting and quantifying changes in species composition.

# SUMMARY OF METHODOLOGIES FOR DETERMINATION OF INSTREAM FLOW NEEDS FOR FISH

## Office Methods

### Hoppe Method

Author(s) & Source: Hoppe, 1975

Output of Method & Key Parameters Considered: Flow recommendations for spawning, rearing and flushing of fines from gravels.

Fish Species: Salmonids

Application: Any Rocky Mountain trout stream for which flow records are available for development of flow duration curves.

Summary of Field Methods: None

Summary of Office Methods: HP-65 computer program is available. Required data inputs are drainage area and percentiles from flow duration curves.

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | 0 |
| | Office: | 1 |
| No. of Mandays | Field: | 0 |
| | Office: | 1-3 |

Constraints & Limitations: Flow records must be available. Resolution low. Manday requirements high if flow duration curves must be developed by hand. Period of record for gage stations should be adequate (20 years) provided no significant man-caused changes in flow regime have occurred. Provides no guidance for assessing flow-habitat trade-offs.

### Tennant Method

Author(s) & Source: Tennant, 1976

Output of Method & Key Parameters Considered: Recommended flow regimens by six-month period based upon percentages of the average discharge for streams of various fisheries classifications. Flushing flow recommendations also possible. Recommendations are also applicable to recreation, wildlife and related environmental resources.

Fish Species: Cold and warm water species.

Application: Streams of all sizes

Summary of Field Methods: Optional. Arrange to observe, photograph and sample flows of approximately 60%, 30% and 10% of the average discharge of record. Begin with the highest flow desired for study. Take photos of key habitat types and obtain cross section data for widths, depths, and velocities. Repeat for lower flows.

Summary of Office Methods: Obtain USGS or other reliable discharge records and calculate the percentages of the average annual discharge for the study stream reach, free of significant man-caused changes in the flow regime.

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | 1 |
| | Office: | 1 |
| No. of Mandays | Field: | 1-3 |
| | Office: | <1 |

Constraints & Limitations: Should not be applied to spring creeks that have a uniform flow year-round. Flow records must be available. With the exception of the black & white photographs, the field methods are quite ambiguous and weak. Because of this, this method is not recommended for implementation level studies. However, for planning level studies, the method is perfectly acceptable. Period of record for gage stations should be adequate. Provides only minimal guidance for assessing flow-habitat trade-offs. Could result in recommendation of flows rarely available naturally for particular periods of the year.

### NGPRP Method

Author(s) & Source: Northern Great Plains Resource Program, 1974

Output of Method & Key Parameters Considered: Instream flow recommendations on a monthly basis to maintain aquatic life as determined by analysis of flow duration curves.

Fish Species: Warm and cold water species.

Application: Any stream for which flow records are available for development of flow duration curves.

Summary of Field Methods: None

Summary of Office Methods: Available streamflow data are assembled on a monthly basis and by statistical analysis, subnormal and abnormal months are discarded. Using the "normal" months data, flow duration curves are then developed for each of the 12 months. The instream flow recommendation for each month is then made by selecting that flow which is equalled or exceeded 90% of the time (10 percentile flow).

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | 0 |
| | Office: | 1 |
| No. of Mandays | Field: | 0 |
| | Office: | 1-3 |

Constraints & Limitations: Flow records must be available with adequate period of record (20 years). For lowland streams in particular, care must be taken to see that lethal temperature and dissolved oxygen conditions do not result. Provides no guidance for assessing flow-habitat trade-offs.

## One Flow Method

Author(s) & Source: Sams & Pearson, 1963

Output of Method & Key Parameters Considered: Optimum flow for salmonid spawning.

Fish Species: Salmonids

Application: Oregon streams

Summary of Field Methods: None, if good quality aerial photos of stream available.

Summary of Office Methods: Measure average pool width from aerial photos. Multiply this width by the mean depth and mean velocity over redds obtained from tables of spawning criteria for appropriate species (Q optimum = WDV).

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | 0 |
| | Office: | 1 |
| No. of Mandays | Field: | 0 |
| | Office: | <1 |

Constraints & Limitations: Output is only an optimum flow, with no guidance given for maintenance flow recommendations. Aerial photos must be recent and of good quality, of adequate scale to define riffles and pools. Spawning criteria must be available for the appropriate species and size class of fish. Method provides no incremental analysis potential and would be of little value in a trade-off situation.

# Field/Office Methods

## Waters Method

Author(s) & Source: Waters, 1976a

Output of Method & Key Parameters Considered: Optimum flows for spawning and rearing.

Fish Species: Resident salmonid populations

Application: California streams

Summary of Field Methods: At least 600 depth and velocity measurements are taken along selected cross-channel transects at each study section at each test flow. At least 3 test flows are investigated. Substrate type at each measurement point is recorded and color photos are taken of each transect at each flow. Velocities are taken 0.2 feet above substrate.

Summary of Office Methods: Computer program is used for data reduction and analysis. Outputs of program are plots of habitat quality for various habitat parameters versus flow. Weighting factors for habitat criteria are used to increase biological sensitivity.

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | ≥3 |
| | Office: | 1 or 2 |
| No. of Mandays | Field: | 9-18 |
| | Office: | 3-9 |

Constraints & Limitations: No guidance is given for recommending minimum or maintenance flows based upon the wealth of data which must be collected. If computer not available, office time would be greatly increased. Field time requirements are very high.

## Oregon Method

Author(s) & Source: Thompson, 1972 and 1974

Output of Method & Key Parameters Considered: Minimum and optimum flows for passage, spawning, incubation and rearing.

Fish Species: Salmonids

Application: Oregon streams as well as Hell's Canyon reach of Snake River.

Summary of Field Methods:
Passage: Locate shallow bars most critical to fish passage and mark a linear transect across the shallowest bank-to-bank course. At each of several flows (at least 3) measure the wetted width and take depth and velocity readings across the channel. Typically, several passage transects are measured in a study reach.
Spawning: Select 3 representative gravel bars and mark a transect across the area of each where spawning is most likely to occur. For large rivers where portions of an entire cross-channel transect may be unwadable, a partial (incomplete) transect may be selected. For at least 3 flow levels, measure depths and velocities across each transect.
Incubation: Either (a) calculate 2/3 of the recommended spawning flow or (b) over a range of flows (3 to 5) measure intra-gravel dissolved oxygen content in suitable spawning areas by means of standpipes.
Rearing: Recommended rearing flows based upon field measurements, observations and judgments. Several flow levels are investigated to make an estimate of the flow required to create a suitable rearing environment.

Summary of Office Methods: For spawning and passage, apply species criteria to establish the percent of wetted width (or transect length) usable. Average the flows indicated as needed to meet minimum and optimum criteria for the various transects to arrive at recommended flows for each species. Array recommendations by 1/2 month consistent with periodicity chart. Select highest flow for each 1/2 month. For incubation either (a) calculate 2/3 of the recommended spawning flow or (b) recommend the incubation flow based upon the spawning flow made available to spawning salmonids and the criterion of at least 5.0 ppm intra-gravel dissolved oxygen. The rearing flow recommendation is based upon the following criteria: (a) adequate depths over riffles; (b) pool-riffle ratio near 50:50; (c) approximately 60% of riffle area covered by flow; (d) riffle velocities of 1.0 to 1.5 ft/sec; (e) pool velocities of 0.3 to 0.8 ft/sec.

Manpower Requirements:

| | | | |
|---|---|---|---|
| No. of Persons | Passage: | | |
| | | Field: | 2 |
| | | Office: | 1 |
| | Spawning & Incubation: | | |
| | | Field: | 2 |
| | | Office: | 1 |
| | Rearing: | | |
| | | Field: | 2 |
| | | Office: | 1 |
| No. of Mandays | Passage: | | |
| | | Field: | 3-6 |
| | | Office: | 1-3 |
| | Spawning & Incubation: | | |
| | | Field: | 3-6 |
| | | Office: | 1-3 |
| | Rearing: | | |
| | | Field: | 3-6 |
| | | Office: | 1-3 |

Constraints & Limitations: Fisheries biologist should select transect locations, especially for spawning recommendation. Incubation method is quite weak, but is 1 of only 3 methods currently available. Overall, the Oregon Method is quite thorough and has been used extensively. Primary constraint is the need for at least 3 visits to the study site.

Oregon "Weighted" Usable Width Method

Author(s) & Source: Sams & Pearson, 1963

Output of Method & Key Parameters Considered: Optimum & minimum flows for spawning.

Fish Species: Salmonids

Application: Oregon streams

Summary of Field Methods: Same as Oregon Usable Width Method.

Summary of Office Methods: Same as Oregon Width Method except that additional biological sensitivity is possible by the use of "weighting" factors based on the species spawning criteria.

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | 2 |
| | Office: | 1 |
| No. of Mandays | Field: | 3-6 |
| | Office: | 1-3 |

Constraints & Limitations: Suitable species spawning criteria must be available to determine weighting factors. If not, method would require extremely high amounts of both field and office time to develop such factors.

USFS Region 2 Cross Method (Colorado Method)

Author(s) & Source: Russell & Mulvaney, 1973; Silvey, 1976; Kochman, 1976 (personal communication)

Output of Method & Key Parameters Considered: Fishery maintenance flow recommendation based upon Critical Area requirements.

Fish Species: Salmonids

Application: Rocky Mountain streams

Summary of Field Methods: Biologist selects the Critical Area for the stream reach in question. This is normally the shallowest portion of the shallowest riffle in the reach. Using the Sag-Tape method, a cross-channel transect is established and depths and velocities are measured along it. Water surface slope is also measured and photos are taken.

Summary of Office Methods: R-2 Cross computer program used to synthesize additional flow levels. Flow recommendation then made based on the lowest flow which meets habitat retention criteria.

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | 2 |
| | Office: | 1 |
| No. of Mandays | Field: | 1 |
| | Office: | 1-3 |

Constraints & Limitations: Changing "n" values with changing flow levels can cause errors in synthesizing flow levels. Accuracy of data not as good as if actual field measurements taken at a range of discharges. Requires an experienced stream biologist to select the Critical Area.

USFS Region 4 Method

Author(s) & Source: Herrington & Dunham, 1967; Chrostowski, 1972; Dunham & Collotzi, 1975; Bartschi, 1976

Output of Method & Key Parameters Considered: Minimum flow recommendation to maintain general fish habitat. Applied in Utah for winter flow recommendations.

Fish Species: Primarily resident salmonid

Application: Small mountain streams in Utah, Idaho and Wyoming

Summary of Field Methods: Sample stations are selected prior to entering field from aerial photos and/or topo maps using gradient and valley bottom stratifications. For each sample station, 5 transects are run to obtain hydraulic data at one late summer low flow (index flow). Habitat rated numerically for 4 categories: (1) pool measure, (2) pool structure, (3) streambottom composition, and (4) streamside environment.

Summary of Office Methods: Using computer program for Manning's equation, discharge is estimated for various water stages other than the index flow. Considering the habitat available at the index flow to be 100%, discharge-habitat plots are developed. Generally, the recommended flow is that which maintains 80% of the index flow habitat.

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | 2 |
| | Office: | 1 |
| No. of Mandays | Field: | 1 |
| | Office: | 1-3 |

Constraints & Limitations: Index flow should be a late summer or fall low flow. If not, recommendations could be unrealistically high. Accuracy of data is not as good as if actual field measurements were taken at a range of flows. Has not been applied to streams greater than 150 feet wide.

USFS Region 6 Method

Author(s) & Source: Swank, 1975; Swank & Phillips, 1976

Output of Method & Key Parameters Considered: Optimum flow for fish

production, considering spawning, rearing and food production habitat.

Fish Species: Salmonids

Application: Pacific Northwest

Summary of Field Methods: For each stream reach studied, a channel cross section is selected as representative for each of the 3 fish habitat parameters (spawning, rearing and food production) considered. A transect is then run at each cross section to measure hydraulic features. Transects are marked and rerun at several other flow levels (at least 3).

Summary of Office Methods: Criteria are presented for spawning, rearing and food production. These are applied to the transect data and discharge-habitat plots are drawn. Optimum flow is where each habitat parameter peaks. If possible, flow duration curves are developed to determine % time optimum flow is available.

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | 2 |
| | Office: | 1 |
| No. of Mandays | Field: | 3-6 |
| | Office: | 1-3 |

Constraints & Limitations: Habitat criteria presented by the authors are quite general. Increased accuracy can be obtained by adjusting these criteria for species and size of fish involved. Field time requirements are high. Output of method is optimum flow only, but it does allow evaluation of the habitat trade-offs for other flows.

## Washington Method

Author(s) & Source: Collings, 1972 & 1974

Output of Method & Key Parameters Considered: Optimum and minimum flow recommendations for spawning and rearing (food production).

Fish Species: Salmonids

Application: Streams in Washington.

Summary of Field Methods:
Spawning: Locate 6 likely spawning sites and establish 4 transects across each site (spaced 10 m apart). Measure depth and velocities across each transect for at least 5 different discharges.
Rearing: Same method as for spawning. If suitable criteria are not available, use Wetted Perimeter Method.
Wetted Perimeter Method: Several representative riffles are located and one transect is located in each. Depth-velocity measurements taken across each transect for at least 5 flows.

Summary of Office Methods:
Spawning: For each site at each flow, draw a planimetric map including isolines of equal depth and velocity. On each such map, measure the area which meets the depth & velocity spawning criteria for the species involved. Plot spawning area vs. flow. Peak of this curve is the optimum spawning flow while 75% of optimum flow is considered the minimum flow.
Rearing: Same method as for spawning but using suitable rearing criteria. If criteria are not available, use Wetted Perimeter Method.
Wetted Perimeter Method: Plot wetted perimeter vs. discharge drawn. Optimum flow for rearing is near the inflection point on the resultant curve.

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Spawning: | |
| | Field: | 2 |
| | Office: | 1 or 2 |
| | Rearing: | |
| | Field: | 2 |
| | Office: | 1 or 2 |
| | Wetted Perimeter Method: | |
| | Field: | 2 |
| | Office: | 1 |
| No. of Mandays | Spawning: | |
| | Field: | 10-20 |
| | Office: | 15-30 |
| | Rearing: | |
| | Field: | 10-20 |
| | Office: | 15-30 |
| | Wetted Perimeter Method: | |
| | Field: | 5-10 |
| | Office: | 1-3 |

Constraints & Limitations: Manpower requirements are exceptionally high.

## WRRI Cover Method

Author(s) & Source: Wesche, 1973 and 1974

Output of Method & Key Parameters Considered: Minimum flow recommendation based upon availability of cover.

Fish Species: Brown Trout

Application: Smaller mountain streams (average discharges of 100 cfs or less).

Summary of Field Methods: Transects selected at each change in stream characteristics and run at 4 or more flow levels. Measured flows should range from 10% to 100% of average discharge (if flow records available; otherwise, middle and late summer flows should be sampled). Depth, width and substrate data collected along transects. Q need be measured at only 1 transect. Lengths, widths and associated water depths measured for all overhead bank cover. Length and mean width of study section measured to obtain wetted surface area.

Summary of Office Methods: Cover rating equation used to determine available cover at each flow sampled. Plot of discharge-cover then drawn. Recommended flow is the lowest flow which avoids the range of greatest cover loss.

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | 2 |
| | Office: | 1 |
| No. of Mandays | Field: | $\geq 4$ |
| | Office: | 4-6 |

Constraints & Limitations: Manpower requirements are high. Systematic method of transect location would facilitate ease of application. Not as yet tested on streams having average discharges greater than 100 cfs or for species other than brown trout (testing now underway).

Remarks: Biological sensitivity of method is high. Based on criteria developed by sampling cover preferences of 1160 trout. Significant relationship was found between cover ratings and standing crops of trout supported. Use of R-2 Cross or WSP computer program could reduce field time required.

Idaho Method

Author(s) & Source: White and Cochnauer, 1975; White, 1976; Cochnauer, 1976

Output of Method & Key Parameters Considered: Stream resource maintenance flows for fish passage, spawning and rearing.

Fish Species: White sturgeon, smallmouth bass, channel catfish

Application: Large, unwadable rivers

Summary of Field Methods: Critical areas for spawning, rearing and passage identified by reconnaissance of stream reach. At each critical area, cross-channel transects are run at the lowest practical discharge to measure physical and hydraulic features. For unwadable streams, special equipment such as a boat with motor, direct readout current meter, sounding reel and CB transceiver must be used.

Summary of Office Methods: U.S.B.R. Water Surface Profile computer program used to estimate changes in stream characteristics at any desired discharges. Applicable species habitat criteria for spawning, rearing and/or passage then applied to hydraulic data and habitat-discharge plots are drawn.

Manpower Requirements:

| | | |
|---|---|---|
| No. of Persons | Field: | $\geq 3$ |
| | Office: | 1 |
| No. of Mandays | Field: | $\geq 3$ |
| | Office: | 1-3 |

Constraints & Limitations: Accuracy is not as good as if actual field measurements taken at a range of discharges. Equipment costs are exceptionally high.

Remarks: Method easily applied to wadable streams also.

Bovee Method (Indicator-Species Overriding Consideration Method)

Author(s) & Source: Bovee, 1975

Output of Method & Key Parameters Considered: Recommendation of minimum

discharges for warm water fisheries for fish passage, spawning and rearing.

Fish Species: For passage and spawning in large rivers, paddlefish is indicator species (sauger in smaller rivers). For rearing, stonecat is the indicator species.

Application: Yellowstone River Basin

Summary of Field Methods: For migration and spawning recommendations in stream having paddlefish, the method is the same as the Oregon Usable Width Method. For streams having sauger, but not paddlefish, the method for spawning recommendations is the same as the Washington Method. Washington Method is also used for rearing flows.

Summary of Office Methods: Patterned after Oregon and Washington Methods.

Manpower Requirements:

No. of Persons

| | Oregon | Wash. |
|---|---|---|
| Passage: | | |
| Field: | 2 | 2 |
| Office: | 1 | 1 or 2 |
| Spawn. & Incub.: | | |
| Field: | 2 | 2 |
| Office: | 1 | 1 or 2 |
| Rearing: | | |
| Field: | 2 | 2 |
| Office: | 1 | 1 |

No. of Mandays

| | Oregon | Wash. |
|---|---|---|
| Passage: | | |
| Field: | 3-6 | 10-20 |
| Office: | 1-3 | 15-30 |
| Spawn. & Incub.: | | |
| Field | 3-6 | 10-20 |
| Office: | 1-3 | 15-30 |
| Rearing: | | |
| Field: | 3-6 | 5-10 |
| Office: | 1-3 | 1-3 |

Constraints & Limitations: Primary constraint is lack of documented species criteria for spawning, migration and rearing. Manday requirements are extremely high.

## PROCEDURES FOR APPLYING SELECTED INSTREAM FLOW METHODOLOGIES

Following is a description of the data collection and analysis techniques required to obtain instream flow recommendations using those methodologies which are felt to be of use to Forest Service personnel in Regions 2 and 3. Where possible, the description provided by the original author of the methodology has been used to avoid editorial misinterpretation of his intent.

### One Flow Method (Sams and Pearson, 1963)

The method gives optimum (not minimum) flow for spawning salmonids and is based on the usable width analyses. Stalnaker and Arnette (1976) observed that the One Flow Method is only of use at the reconnaissance level on streams large enough to evaluate width measurements from aerial photos, because "the resolution at the field measure level would be much lower than the transect or mapping techniques."

Office methods are as follows:

1. From aerial photos, separately calculate the average stream width and average pool width.

2. Multiply average pool width times mean depth and mean velocity of water obtained by measurements over redds of the species concerned. Q (optimum spawning flow) = WDV.

Notes:

1. The method is safe for use if average stream width (W) is near average pool width. At flows too low for the method, the riffles are narrower than the pools.

2. The mean depth (D) and mean velocity (V) over redds can be obtained from tables of species criteria.

### USFS R-6 Method (Swank, 1975; Swank and Phillips, 1976)

The R-6 Method determined the optimum streamflow for fisheries purposes. Swank (1975) stresses that the optimum flow is not necessarily the lowest streamflow satisfactory for fisheries but rather that flow with the greatest amount of usable habitat, evaluated from the standpoint of three different fisheries life functions (spawning, rearing, and food producing).

Equipment list for field methods includes the following: (1) transect stakes and hammer, (2) waders, (3) tape measure, (4) current meter, (5) depth rod, (6) field data forms, and (7) stop watch.

The field procedure is as follows:

1. Select typical channel cross sections to represent spawning, rearing and food producing habitat present in the stream reach.

2. Establish permanent cross channel transects for flow measurements at the cross sections.

3. Measure depths and velocities along the transects for at least three flows representing high flow, low flow, and near average flows. Ideally, the more measurements, the better.

Once these data are collected and recorded, the actual optimum flow determination is made in the office.

Office methods are as follows:

1. Calculate the usable width of each cross section at each flow measured for the life function of interest. Swank (1975) gives the following salmonid criteria and suggests adjustments for each particular stream and species:

| Criteria | Depth (ft) | Velocity (fps) |
|---|---|---|
| Spawning | <0.5 | 1.0-3.0 |
| Rearing | 0.5-3.0 | 0.2-1.6 |
| Food Producing | 0.1-3.0 | 1.0-4.0 |

2. Plot usable width for each life function versus flow and draw the curve. The optimum flow is where each criteria curve peaks.

3. Select the optimum flow from the three choices. This depends on the magnitude of usable width differences between the peaks and on the characteristics of the stream itself. If the range of flows is not too great, the optimum can be expressed in a range of values.

4. A flow duration curve can be developed to determine the percentage of the time optimum flow or range can be expected.

Example Optimum Flow Duration (Swank, 1975)

North Fork of the Crooked River. The North Fork fluctuates seasonally with extremes of from 1500 cfs to less than 1 cfs. Three types of sections were selected to represent the various rainbow trout habitats. Flows were measured at selected sites at high, low, and near average discharges. The data obtained were plotted as shown in Figure 4. Optimum flow is shown to be 35-40 cfs, and from the duration curve (Figure 5) it can be seen that

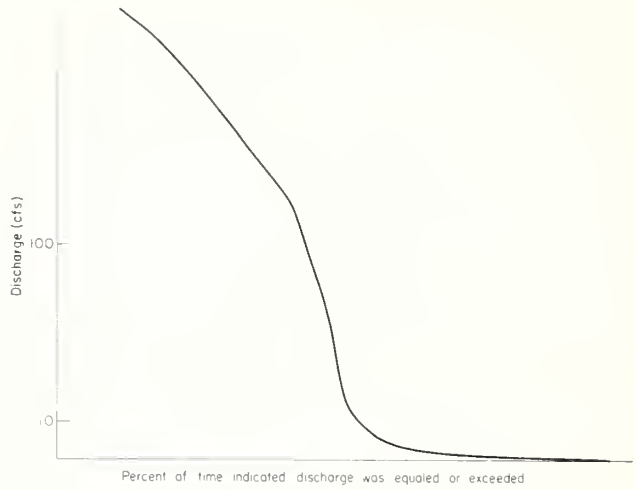



Figure 5. Flow duration curve (from Swank, 1975).

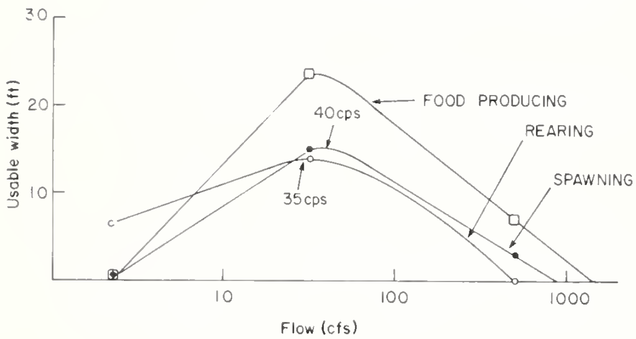



Figure 4. North Fork of the Crooked River instream flow analysis (from Swank, 1975).

this flow is exceeded 45-50 percent of the time. If this optimum could not be obtained, habitat loss can be estimated from the figures. For example, a reduction in rearing flow from 35-40 cfs to 5 cfs results in a habitat reduction of 14 feet of usable width to 9 feet (a loss of about 35 percent).

Swank (1975) lists opportunities and limitations of the method as follows:

Opportunities: (1) Can subjectively evaluate the tradeoffs. (2) Can be used at established stream gaging sites (that meet site requirements). (3) Can be used to develop interim flows for ungaged areas pending more detailed field investigation.

Limitations: (1) Unless the stream is or has been gaged, visits to the site over a range of flow conditions are needed to adequately define the curve. (2) Where existing gaging station flow measurements are used, it is important to use only those measurements that were taken at the exact same channel cross section. (3) Depending on channel hydraulics several bell-shaped curves can result if excessively high flows are used. For example, the amount of usable width to flow may decrease as flow increases up to a point; then as the water continues to rise even higher--perhaps even out-of-the-bank flow occurs--the slack water along the edges causes the ratio of usable area to flow to increase, causing a second bell-shaped curve. When this occurs, usually other overriding factors such as quality, accessibility, etc., rule out subsequent peaks for an optimum flow. (4) While a flow duration curve is not an essential tool of this procedure, it is helpful to characterize streamflow. It is difficult, however, to develop such curves for ungaged or short-term stations.

## Tennant Method
(Tennant, 1975 and 1976)

One of the best known and most widely used and accepted of the instream flow determining methodologies, the Tennant Method was developed after 10 years of research on 58 stream cross sections at 38 different flows. It is based on percentages of the average annual flow as obtained from USGS hydrological data (listed as AVERAGE DISCHARGE). Results indicate that the condition of aquatic habitat is similar for most streams carrying the same portion of the average flow. Results are consistent from stream to stream or state to state.

Equipment list (if field data are needed) for field methods includes the following: (1) camera and film, (2) waders, (3) tape measure, (4) depth rod, (5) current meter, (6) data forms, and (7) stop watch.

As described by Tennant (1976), field methods (optional) consist of the following:

1. After determining the average annual flow (average discharge), visit the stream and observe, photograph, and study flows approximating 10 percent, 30 percent and 60 percent of the average flow (average flow obtained from Water Supply Papers, as in Table 1). If discharge records are not available, they may be estimated.

2. Pictures are important. Black and white photos of key habitat types from elevated vantage points at each different flow will substantiate the final recommendation. All photos and slides should be properly labeled with vital information immediately after processing.

3. Obtain cross sectional data on width, depth, and velocity for each flow. These may be obtained from the USGS for a reasonable fee, or can easily be done by a fieldman using the Tight-Tape Transect Technique.

Once the field measurements for the three flows have been gathered the following office techniques can be used to complete the recommendation:

1. Study the USGS records for flow patterns, average daily streamflow regimens and previous historical low flow data to learn base flow patterns of the climatic year.

2. Using those records and Table 2, recommend base flow regimens which are the most appropriate and reasonable that can be justified to provide protection and habitat for all aquatic resources.

## NGPRP Method
(NGPRP, 1974)

The NGPRP methodology was developed out of a need for a strictly office method of recommending instream flows for aquatic life. It is based on existing and reasonably available hydrological records of the USGS. A basic assumption is that water presently flowing past a recording gage represents the flows supporting present levels of aquatic and related resources. The unit of time selected for analyzing instream needs was the calendar month. Because it assumes that the more stabilized and representative biological components of an aquatic system are largely supported by a norm or average hydrologic condition rather than by short-term patterns, the methodology centers on deriving estimates of streamflow needs based on average hydrologic conditions for each specific month. It also has provisions, however, for estimating flow needs for extremely dry periods.

The office method is as follows (from NGPRP, 1974):

1. "The first step was to assemble all the hydrologic streamflow data available for a given area and segregate the information by month. All of the data pertaining to a specific month for the period of record were then subdivided, on the basis of the average monthly flow, into groupings representing subnormal (dry), average, and abnormal (wet) conditions. Note that if the period of surface water record is 20 years, then the sample size for the month of August is 20.

"Delineation based on the variability of the average monthly flow data was thought to be less biased and more representative of actual streamflow conditions than would be simply assigning an inflexible percentage figure above and below the average flow for the period of record to isolate and group the data into subnormal, average, and abnormal categories. The Student's "t" statistic was selected for the analysis. (A detailed discussion on the use of this statistic can be found in most standard statistics textbooks.) Since the distribution of "t" with an adequate sample size is bell-shaped and approaches a normal distribution, an equal number of the average monthly flow values should fall above and below the mean. Theoretically, a large percentage of the individual values will cluster around the mean with fewer and fewer observations occurring with the increasing distance from the mean. The objective was therefore to delete those months with average flows falling at a distance from the mean for the period of record. By adding and subtracting

Table 1. Platte River Basin, 06657500, Laramie River near Glendevey, Colorado.

LOCATION - Lat. 40°48'02", long. 105°52'40", in NW¼NW¼ sec. 36, T.10 N., R.76 W., Larimer County, on left bank 200 ft (61 m) downstream from bridge on county road, 350 ft (110 m) downstream from Nunn Creek, 1,500 ft (400 m) upstream from Stub Creek, and 3.0 mi (4.8 km) east of Glendevey.

DRAINAGE AREA - 101 $mi^2$ (262 $km^2$).

PERIOD OF RECORD - June 1904 to October 1905, August 1910 to current year. Monthly discharge only for some periods, published in WSP 1310. Published as "at Glendevey" 1905, 1910 18.

GAGE - Water-stage recorder. Altitude of gage is 8,230 ft (2,509 m), from topographic map. See WSP 1730 for history of changes prior to Sept. 20, 1935.

AVERAGE DISCHARGE - 64 years, 73.8 $ft^3/s$ (2.090 $m^3/s$), 53,470 acre-ft/yr (65.9 $hm^3/yr$).

EXTREMES - Current year: Maximum discharge, 900 $ft^3/s$ (25.5 $m^3/s$) June 11, gage height, 3.41 ft (1.039 m); minimum daily, 14 $ft^3/s$ (0.40 $m^3/s$) January 28.

Period of record: Maximum discharge, 2,240 $ft^3/s$ (63.4 $m^3/s$) June 9, 1923, gage height, 4.55 ft (1.387 m), site and datum then in use, from floodmarks, from rating curve extended above 1,400 $ft^3/s$ (40 $m^3/s$); minimum daily recorded, 5.0 $ft^3/s$ (0.14 $m^3/s$ Feb. 14, 15, 1911, but may have been less during winter periods of no gage height record.

REMARKS - Records good. Diversions for irrigation of about 700 acres (2.83 $km^2$) of hay meadows above station. Transbasin diversions above station to Cache la Poudre River and tributaries.

REVISIONS (WATER YEARS) - WSP 469: 1911-12. WSP 506: Drainage area. WSP 1310: 1905, 1914. WSP 1918: 1918 (monthly runoff).

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1972 TO SEPTEMBER 1973

| Day | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 38 | 41 | 23 | 15 | 16 | 17 | 17 | 43 | 292 | 352 | 57 | 22 |
| 2 | 34 | 37 | 24 | 15 | 16 | 17 | 17 | 35 | 318 | 331 | 60 | 22 |
| 3 | 33 | 36 | 23 | 15 | 16 | 17 | 17 | 34 | 266 | 280 | 53 | 50 |
| 4 | 31 | 38 | 22 | 15 | 16 | 18 | 17 | 44 | 224 | 203 | 52 | 53 |
| 5 | 34 | 36 | 22 | 15 | 16 | 18 | 17 | 56 | 203 | 176 | 61 | 49 |
| 6 | 34 | 34 | 22 | 15 | 16 | 18 | 17 | 66 | 235 | 170 | 57 | 47 |
| 7 | 33 | 34 | 22 | 15 | 17 | 18 | 17 | 69 | 296 | 156 | 51 | 53 |
| 8 | 38 | 36 | 22 | 15 | 17 | 18 | 17 | 80 | 380 | 132 | 47 | 49 |
| 9 | 40 | 32 | 22 | 15 | 17 | 18 | 17 | 108 | 487 | 123 | 41 | 47 |
| 10 | 36 | 31 | 22 | 15 | 17 | 18 | 18 | 117 | 736 | 112 | 37 | 52 |
| 11 | 33 | 31 | 22 | 16 | 17 | 18 | 18 | 117 | 820 | 98 | 39 | 63 |
| 12 | 31 | 31 | 22 | 16 | 16 | 18 | 20 | 119 | 754 | 100 | 37 | 58 |
| 13 | 31 | 31 | 22 | 16 | 16 | 18 | 21 | 123 | 759 | 152 | 34 | 50 |
| 14 | 32 | 31 | 22 | 16 | 16 | 18 | 23 | 134 | 786 | 188 | 31 | 45 |
| 15 | 37 | 31 | 21 | 16 | 16 | 18 | 25 | 145 | 764 | 135 | 30 | 43 |
| 16 | 49 | 31 | 21 | 17 | 16 | 18 | 22 | 172 | 565 | 115 | 29 | 41 |
| 17 | 44 | 31 | 21 | 17 | 15 | 18 | 23 | 206 | 455 | 91 | 29 | 39 |
| 18 | 50 | 30 | 20 | 17 | 15 | 18 | 25 | 254 | 428 | 82 | 29 | 38 |
| 19 | 48 | 29 | 20 | 17 | 15 | 18 | 21 | 328 | 345 | 105 | 28 | 36 |
| 20 | 44 | 28 | 19 | 17 | 15 | 18 | 22 | 402 | 296 | 144 | 26 | 35 |
| 21 | 54 | 27 | 19 | 16 | 15 | 18 | 22 | 444 | 314 | 142 | 26 | 33 |
| 22 | 53 | 26 | 18 | 16 | 15 | 18 | 22 | 387 | 311 | 93 | 26 | 32 |
| 23 | 47 | 25 | 18 | 16 | 15 | 18 | 22 | 398 | 248 | 75 | 26 | 32 |
| 24 | 45 | 24 | 17 | 16 | 16 | 18 | 22 | 410 | 296 | 132 | 26 | 32 |
| 25 | 42 | 23 | 17 | 16 | 16 | 18 | 23 | 376 | 289 | 181 | 26 | 34 |
| 26 | 41 | 22 | 17 | 15 | 16 | 18 | 23 | 352 | 373 | 169 | 24 | 40 |
| 27 | 42 | 22 | 17 | 15 | 17 | 18 | 26 | 277 | 380 | 79 | 23 | 37 |
| 28 | 40 | 21 | 17 | 14 | 17 | 18 | 34 | 251 | 335 | 63 | 22 | 44 |
| 29 | 36 | 21 | 17 | 15 | -- | 18 | 47 | 254 | 292 | 64 | 22 | 47 |
| 30 | 32 | 22 | 16 | 16 | -- | 17 | 52 | 254 | 328 | 79 | 21 | 49 |
| 31 | 43 | -- | 15 | 16 | -- | 17 | -- | 243 | -- | 68 | 21 | -- |
| Total | 1,225 | 892 | 822 | 486 | 448 | 553 | 884 | 6,298 | 12,578 | 4,390 | 1,091 | 1,272 |
| Mean | 39.5 | 29.7 | 20.1 | 15.7 | 16.0 | 17.8 | 22.8 | 203 | 419 | 142 | 35.2 | 42.4 |
| Maximum | 54 | 41 | 24 | 17 | 17 | 18 | 52 | 444 | 820 | 352 | 61 | 63 |
| Minimum | 31 | 21 | 15 | 14 | 15 | 17 | 17 | 34 | 203 | 63 | 21 | 22 |
| Ac-ft | 2,430 | 1,770 | 1,230 | 964 | 889 | 1,100 | 1,360 | 12,490 | 24,940 | 8,710 | 2,160 | 2,520 |

| | | | | | |
|---|---|---|---|---|---|
| Cal yr 1972 | Total 25,605 | Mean 70.0 | Max 708 | Min 15 | Ac-ft 50,790 |
| Wtr yr 1973 | Total 30,536 | Mean 83.7 | Max 820 | Min 14 | Ac-ft 60,570 |

Source: U.S. Department of the Interior, 1973.

Table 2. Instream flow regimens for fish, wildlife, recreation and related environmental resources.

| Narrative Description of Flows[1] | Fisheries Class.[2] | Recommended Base Flow Regimens (Percentage of average flow) Oct-Mar | Apr-Sept |
|---|---|---|---|
| Flushing or Maximum | -- | 200[3] | |
| Optimum Range | -- | 60-100[4] | |
| Outstanding | I | 40 | 60 |
| Excellent | II | 30 | 50 |
| Good | III | 20 | 40 |
| Fair or Degrading | IV | 10 | 30 |
| Poor | -- | 10 | 10 |
| Severe Degradation | -- | | |

[1]Most appropriate description of the general condition of the streamflow for all the parameters listed in the title of this paper.

[2]Roman numeral ratings for Fisheries Classification Systems like those developed for the States of Idaho, Montana, West Virginia, Wyoming, and the Delaware River Basin Comprehensive Study by the U.S. Fish and Wildlife Service.[5,11,14,19,26] The base flow regimens outlined above in columns 3 and 4 to maintain the respective designated classes, are judged to be as reliable and valid as the classification systems themselves. These recommended flows generally apply very well to both cold and warm water streams. Regimens should be reversed or altered to fit different hydrologic cycles, like the Salmonid streams on the West Coast, or to favor species like the fall spawning brown trout. Flows may be refined further by specifically matching them to vital periods of the life cycle of fishes, like migration, spawning, incubation, growth, etc. Use of the Montana Method on spring creeks or streams that have a very uniform flow year-around may provide unprecedented low-flow regimens at the minimum or base flow levels.

[3]The average flow will usually fill the active stream channel approximately 1/3 full or to the line of permanent terrestrial vegetation, while 3 times the average flow will often fill the active channel approximately to the point of spilling out on the first bench of the flood plain.[15] Twice the average flow will produce effective depths and velocities within the stream channel for moving silt, sediment and other bed load material without doing extensive damage to the banks and riparian vegetation. Twice the average flow is a good maximum flow recommendation as well as a good flushing flow.

[4]Optimum is a nebulous term; however, this flow range covers that definition best for all the parameters of this paper collectively.

[5]Source: Tenant, 1975.

the variable $t_x(s) \div \sqrt{n}$ to and from the monthly mean for the period of record, upper and lower limits are established between which is a given percentage of the observations. In the initial testing of this procedure on several stream reaches, it appeared that 70 percent of the months should be considered as representing average hydrologic conditions and 30 percent should be deleted. The 30 percent theoretically should be divided equally between subnormal and abnormal months. However, if the data are variable and slightly skewed, a larger percentage of below average months, for example, may be deleted and correspondingly fewer above average months. The reverse situation could also be true. Although deviation from normality was common in the delineation, and although the use of such a statistic in such cases and in the manner outlined above is questionable, its use as a tool to accomplish the objective appeared to be adequate and representative of the hydrologic conditions for many stream systems and stream reaches studied. Conditions where this procedure could not be used are discussed later.

2. "The second step involved compiling the daily flows for each of the "normal months" (as determined by the procedure above) and arraying these from the lowest to the highest. From this array the stream flow [which was] exceeded 90 percent of the time was determined, and this was considered as the initial (base line) estimate of instream need and is referred to hereafter as the 10 percentile flow. For example, if the number of years in which August was considered "normal" is 20, there would be 620 integrated daily flows arrayed from the lowest to the highest value. If the array was divided into 10 groups, each group would contain 62 values. The first 62 values would represent 10 percent of the data, and the last value in this group (62nd value) would be the 10 percentile value flow. The hydrologic data were computerized so that the 10 percentile flow for "normal months" would be displayed.

"Selection of the 10 percentile flow was somewhat arbitrary. We assumed that flow is a major controlling factor in an aquatic ecosystem and the lowest flow or flows are more controlling. Generally, however, one day or so at the lowest flow may actually do little harm, but several days at the lowest flow might considerably impair the ecosystem. Under examination the data appeared to support elimination of flows representing the lowest 10 percent of the samples, although this decision must be considered largely as a subjective [decision of the fishery specialists examining the hydrology data.]

"Assuming daily flows for a specific month are similar year after year, then theoretically the three lowest flows should be deleted for each "normal" month considered. In reality, similarity in flows year after year holds only to a limited degree. For this reason, the daily flows within the samples were arrayed as previously described and the 10 percentile value subsequently identified. In this manner, the more damaging low flows over the "normal" period were selectively eliminated.

"In those sections of stream with an extremely important aquatic resource such as a natural trout stream in a mountainous area or in some of the larger stream systems, streamflow is characteristically much more stabilized during the critical winter and summer months, and variation in the daily flows within a month and year after year is much less. It was observed that in such a relatively "flat" flowing stream, the 10 percentile flow for "normal months" is generally not too significantly different from a 20 percentile flow (flow exceeded 80 percent of the time) or in some cases from even a 50 percentile flow (flow exceeded 50 percent of the time) if the entire period of record, without deletion of abnormal and subnormal periods, is used. It was therefore felt that the 10 percentile flow would usually maintain the essential aspects of an aquatic ecosystem at a high level in generally more important areas and at a somewhat lower level in less important areas. This appears reasonable since organisms adapted to more stable systems usually are less tolerant or adaptable to environmental change (such as coldwater fish species) than are those subjected to highly fluctuating systems (such as warmwater fish species in plains streams). . . .

3. "In the third step, the instream estimates derived by the analyses outlined above were adjusted to compensate for known quantities of water entering or leaving the stream system within the study reaches. This was necessary because of the criteria used in delineating stream study reaches and the location of gaging stations in relation to the designated reaches. A major stream was divided into several sections with the dividing line between sections generally represented by a major tributary entering the system or by a major diversion removing water from the stream. Water was added or subtracted accordingly, where information was available. Since the expressions of instream needs were applied to the downstream boundary of each stream study section, this seemed to be a logical and necessary approach. Delineation of study reaches by this procedure sometimes coincided with major changes in the types of fisheries.

4. "The final adjustment [in estimating the] instream need for "normal" periods was based largely on knowledge of the types of fishery resources in the study reaches and of specific species requirements. This, in some cases, modified the estimates when there were biological considerations related to patterns in the flow data. However, these adjustments to the values derived by the data analysis in the second step and adjusted in the third step were generally of minor significance.

"Because fishery data represent the bulk of what is known about the aquatic resources in the study area, many of the adjustments in the calculated estimates focused on this component of the ecosystem, with the general assumption that environmental conditions suitable for fish would also represent the requirements for most of the other aquatic organisms present.

"In considering the seasonal pattern of flow, minor adjustments were made in calculated values for ease in handling the data. For example, if the computed instream estimates and subsequent adjustments indicated a flow of 100, 95 and 100 cfs for December, January and February, respectively, the 95 cfs for January was adjusted upward to 100 cfs. If the computed flows were 105, 95, and 100 for the same periods, the first two flows were adjusted to 100 cfs. Decisions on the direction and extent of such adjustments were based on "natural groupings" of several consecutive months.

"The same procedure (Steps 1 through 4 above) was applied to each of the 12 months. However, the spring runoff period posed a special problem since the presumed seasonal flooding necessary to maintain riparian and associated wildlife habitat is poorly documented for the study area. Also poorly understood are channel flushing requirements to prevent encroachment of vegetation and clean spawning gravels or to properly flood other spawning habitat. The freshening effect, which may initiate spawning and other movement of some fish species, is another poorly known requirement. Therefore, we arbitrarily selected a figure near the mean annual flow of record for the high runoff period, assuming from a fisheries standpoint that such flows would generally keep channels open and clean and would reasonably maintain spawning conditions for many or most species. This appeared acceptable for the present study, but detailed field studies are essential to determine adequate flow needs during this period. Generally, to a somewhat lesser degree, field studies are essential for all periods of the year.

5. "The unusually "dry" months deleted in the statistical analysis, Step 1, were treated separately under the assumption that the ecosystem and all other water uses may be seriously impacted when such a condition occurs. Since this happens occasionally as a result of nature, it was decided by the work group that a "sharing" of the shortage would be a logical approach. In these cases, since flow shortages can be broadly predicted as a percentage of normal, it was decided

that such predicted percentages should apply to the instream water needs determined for "normal" conditions. However, . . . it was necessary to deviate from this procedure because of later developing computer programming difficulties. These particular departures in the way the "dry" month data were handled were for practical reasons and should not be construed as conceptual changes."

### Hoppe Method
(Hoppe, 1975)

The method is based on percentile levels of the flow duration curve and various activities in the life history of the species present. A preliminary study on the Frying Pan River, Colorado, showed recommended flows for spawning, cover and flushing corresponded with 40th, 80th, and 17th percentiles, respectively, on the flow duration curve.

Office methods are as follows:

1. Acquire flood records from USGS or other source.

2. Develop a flow duration curve (Figure 5) by counting the number of days, weeks, months, or years with flow in various class intervals. As the length of time unit increases, the range of the curve decreases. The selection of the time unit depends on the purpose of the curve. Therefore, for absolute minimum historical flow determination, a daily time unit should be used (Linsley and Franzini, 1972).

3. From the developed duration curve, the flow that is equalled or exceeded 17 percent of the time is recommended for a 48-hour flushing flow; the flow that is equalled or exceeded 40 percent of the time is recommended for spawning; and that flow equalled or exceeded 80 percent of the time is recommended for food production and cover.

Stalnaker and Arnette (1976) describe the following equations to be used for approximating 40 and 80 percentile discharges for specific points between gaging stations:

$$Q_{80} = \text{antilog } [\cosh^{-1} (\log A - 0.60)\ 1.43]$$

and

$$Q_{40} = \text{antilog } [\cosh^{-1} (\log A - 0.55)\ 1.53]$$

where

$Q_{80}$ = the 80 percentile discharge level;

$Q_{40}$ = the 40 percentile discharge level; and

A = the drainage area in square miles.

Another way to approximate $Q_{80}$ and $Q_{40}$ is to develop a log-log plot of drainage area versus $Q_{80}$ (taken at gaged points) and interpolated from the resulting graph (Stalnaker and Arnette, 1976).

### USFS Region-2 Cross Method
(Colorado Method or Critical Area Method)
(Russell and Mulvaney, 1973; Silvey, 1976; and Kochman, 1976, personal communication)

The Critical Area approach to establishment of instream flow consists of using an interdisciplinary field team, each member of which makes a determination of the flow needed to maintain desirable qualities for his discipline. The field techniques used are as follows:

1. After extensive office study of maps, water diversions and basic data available on the selected stream or reach, the field team (consisting of a hydrologist, biologist, landscape architect, water quality specialist, and anyone else as needed to provide input where instream flows are important for other uses) tours the study area.

2. Each team member identifies, by visual observation, certain areas (Critical Areas) on the reach which would be most useful to him for studying the parameters important to his disciplinary use for instream water. These Critical Areas contain the limiting factors for streamflow for a particular parameter in that stream reach. It is assumed that if conditions are sufficient for each parameter at the Critical Area, they will also be sufficient at all other areas represented in the reach. Normally, the critical fisheries area is considered to be the shallowest cross section of the shallowest riffle in the reach being investigated.

3. The Critical Areas are marked and photographed.

4. Cross-channel transects are established to represent each Critical Area, and

a cross section profile, consisting of depths and velocities at regular intervals, is measured. A master reference point is established upstream from the study reach and stage determined.

Office methods consist of the following:

1. Conduct a preliminary literature review and detailed study of the reach under investigation.

2. After the field investigation, the cross section data are applied to Manning's formula to synthesize the flow in the channel at various levels. Figure 6 provides an example of the synthesized flow.

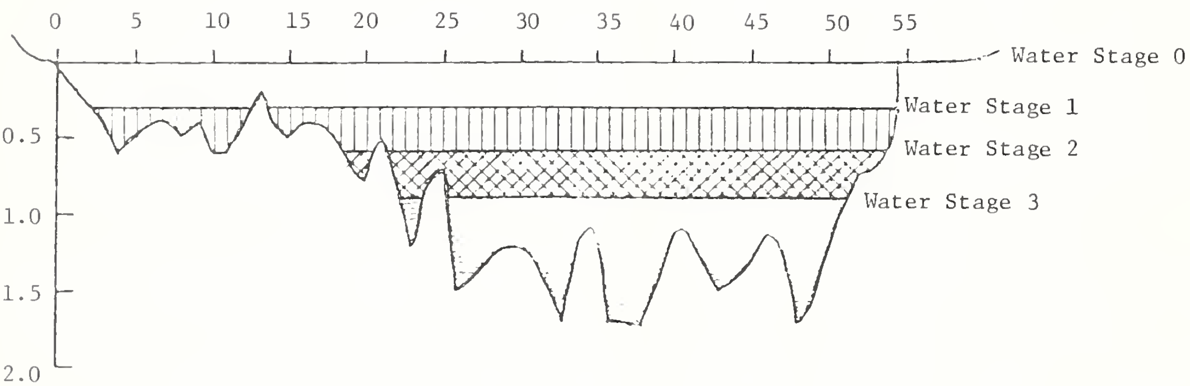
3. Based on the various synthesized flow levels, each discipline specialist identifies the absolute minimum flow at each Critical Area needed to meet minimum criteria for the parameters represented. Following this, he determines an optimum flow in the same manner. For Fisheries criteria, the State of Colorado (Kochman, personal communication) uses the flow which (1) wets 50 percent of the total bank-to-bank perimeter; (2) maintains a mean velocity across riffles of 1.0 to 1.5 feet per second; and (3) maintains the following depths:

0.2-0.4 ft for streams < 20 feet wide; and

0.5-0.6 ft for streams > 20 feet wide.

The recommendation is then "custom-fit" to each stream to meet at least one, two, or all three of the above criteria. These criteria have worked well for coldwater fisheries but should not be applied to warmwater situations.

Scale: Horizontal 1" = 10 ft
Vertical 1" = 1 ft




| Water Stage | Discharge cfs | Discharge % | Velocity fps | Velocity % | Max. Depth ft | Max. Depth % | Ave. Depth ft | Ave. Depth % | Area sq ft | Area % | Water Surface ft | Water Surface % | Wetted Perimeter ft | Wetted Perimeter % | Habitat Retained opt | Habitat Retained % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 52.07 | 100 | 1.04 | 100 | 1.8 | 100 | 0.9 | 100 | 49.87 | 100 | 53.3 | 100 | 54.4 | 100 | 63% | 100 |
| 1 | 27.65 | 53 | 0.82 | 79 | 1.5 | 83 | 0.7 | 78 | 33.72 | 68 | 51.0 | 96 | 53.0 | 96 | 56% | 91 |
| 2 | 14.48 | 28 | 0.73 | 70 | 1.2 | 67 | 0.6 | 67 | 19.84 | 40 | 35.4 | 66 | 37.2 | 67 | 48% | 80 |
| 3 | 8.44 | 16 | 0.66 | 64 | 0.9 | 50 | 0.4 | 44 | 12.80 | 26 | 26.2 | 49 | 27.9 | 50 | 41% | 69 |

Source: Russell and Mulvaney, 1973.

Figure 6. Example of synthesized flow.

4. Determine seasonal variations in flow needs for fisheries, aesthetics, and other purposes.

5. Flows determined for Critical Areas are then related to a stage at a master reference point. This relates all Critical Areas to one stage-discharge relationship.

6. Present a package including range of flows for various parameters related to fishery, aesthetic and other instream flow users to the administrator.

### USFS Region 4 Method
(Herrington & Dunham, 1967; Chrostowski, 1972; Dunham & Collotzi, 1975; Bartschi, 1976)

The Region 4 methodology for determining instream flow needs in streams from 4 to 150 feet wide is based upon a habitat survey sampling procedure using cross-channel transects to quantify habitat variables. This is accomplished through the following general steps:

1. Study site is selected and the habitat present at a low summer flow ("index flow") is inventoried.

2. Using the data from Step 1, a habitat rating value is determined for the index flow.

3. Either using a computer program such as R-2 Cross or calculating Manning's equation by hand, synthesized channel cross sections are derived for water stages other than the index flow.

4. Habitat rating values are determined for the computed water stages and are expressed as a percentage of the index flow value.

5. A plot is then drawn of percent of index flow versus percent of index flow habitat value.

6. From this plot, the lowest acceptable resource maintenance flow is selected which will allow retention of at least 80 percent of the index flow habitat value.

To conduct the field portions of this methodology the R-4 equipment list includes the following: (1) transect stakes and hammer, (2) waders, (3) depth rod, (4) tape measure (50 or 100 feet), (5) Abney level or clinometer, (6) field data sheets, (7) stream velocity meter, (8) camera and film, (9) map or aerial photos.

Data Gathering Techniques (from Herrington and Dunham, 1967; and Dunham and Collotzi, 1975)

1. Before leaving for the field, study streams and their sample stations are located on available aerial photos or maps.

2. Field crews then locate the selected areas and, to eliminate bias, establish the first transect 100 feet upstream from the point first identified on the ground and at 50 foot intervals thereafter for a total of 10 transects or 450 feet. Chrostowski (1972) found that reducing the total number of transects per sampling station to 5 (250 feet) did not affect statistical validity.

3. Each transect extends across the entire channel (for braided sections, all channels should be included) at a 90 degree angle to the centerline. Along each transect then, the following habitat and cross section data should be collected:

    a. Channel Width - to the nearest tenth of a foot as measured between the high water marks.

    b. Total Width - the wetted width of the channel to the nearest tenth of a foot at the time of the survey.

    c. Water Depth - to the nearest tenth of a foot at point locations across the transect. Note: The sag or tight tape technique of transect measurement should be used to allow for the synthesis of cross sections at other water stages.

    d. Velocity - 0.2-0.8 or 0.6 of depth method. Note: Velocity need only be measured across one transect at a sample station to obtain a discharge measurement. Be certain, of course, that flow deletion or accretion does not occur between your upper and lower transects.

    e. Riffle Width - total width minus pool widths across the transect.

    f. Pool Measures - for each pool area across the transect, width, rating (as obtained from Figure 8), location and feature are measured. Each pool is recorded as in contact with right or left bank or as center if not bank-associated. Significant features of

pool cover are recorded such as boulder, overhanging bank, water depth, surface turbulence, and vegetation, if tree roots form a major feature of the pool. Record linear measurements of rooted aquatic vegetation occurring along the transect.

g. Streambottom - measure lineal footage of each type of bottom material along the transect and record to the nearest foot.

h. Bank Environment - right and left banks are identified while facing downstream. Bank environment is the class of vegetation precisely at and overhanging the transect points at the water's edge. Three types of vegetation are recognized: (1) forested - streambanks bordered by growth of tall trees; (2) brush - streambanks bordered by dense growth of low brush (willows, alders, hawthorne, etc.); (3) exposed - streams flowing through pasture and meadow areas with only grasses and low herbs for vegetation.

i. Bank Stability - at each bank point. An unstable rating is given if there is evidence of soil sloughing in the past year. On multiple channels, only the two outermost banks are rated.

j. Slope

k. Comments - includes pertinent observation comments such as water stage, fish, beaver activity and ponds, obstructions, manmade features, access, suspended pollution, etc. Sketches of valley bottom cross section, stream channel profiles and discharge measurement may also be included.

Computer Program. To facilitate the handling and manipulation of these data as well as other pertinent stream identification data, Collotzi (1975) has developed the 3 computer forms presented in Figures 7, 8 and 9. The following instructions, definitions and coding information regarding their use is taken directly from Collotzi (1975).

"Introduction. This computer program provides the fisheries biologist with the opportunity to store aquatic habitat inventory data. Once these data have been stored they can be manipulated using various programs already developed for the computer, or they can be recalled as they were placed in the computer for later reference. Naturally, the value of the output information is directly proportional to the quality of the raw data input. Neatness and accuracy are absolutely necessary on the data format forms.

Three separate forms are used for this program. One form, the Stream Identification Form, is used for each stream and can be filled out in the office. The second form, the Stream Station Form, is to be used for each station on the stream, and has been designed for use in the field. The third form, the Instream Flow Form, is to be used at stations needing instream flow requirements. If used properly, the forms can be photocopied and the copy sent to the computer center. The original is to be filed with your records.

Stream Identification. The Stream Identification Form has been designed to identify a given stream to the computer. Information on this form occupies one card of 80 spaces. This form can be completed in the office. The items on this form need to be completed as follows:

Item 1 - Card Code. This item requires no entry.

Item 2 - Catalog Number. The catalog number for any given stream is that used by the state. Place the catalog number to the far left and leave the remaining spaces blank. Using this number will provide for an exchange of data between the forest and the state.

Item 3 - State. Check the appropriate square.

Item 4 - Forest. Check the appropriate square.

Item 5 - This item will locate the stream at its mouth or at the forest boundary, using longitude and latitude.

Item 6 - Total Length. Enter the total length of the stream located within the forest boundary.

Item 7 - Stream Order. Enter stream order as identified by hydrologist.

Item 8 - Name of Stream. Write the name of the stream, if available.

STREAM AQUATIC HABITAT INVENTORY

Stream Identification Form

Stream ______________________________ Forest ______________________________

Date ________________________________ Investigator ________________________

1 - Card 1

2 - Catalog No. [ | | | | | | | | | | | | | ]

3 - State

__ California
__ Idaho
__ Nevada
__ Utah
__ Wyoming

4 - Forest

__ Ashley
__ Boise
__ Bridger-Teton
__ Caribou
__ Challis
__ Dixie
__ Fishlake
__ Humboldt
__ Manti-Lasal
__ Payette
__ Salmon
__ Sawtooth
__ Targhee
__ Toiyabe
__ Uinta
__ Wasatch

5 - Location Longitude [ | | | | ]

Latitude [ | | | ]

6 - Total Length [ | | | ]

7 - Stream Order [ | ]

8 - Name of Stream [ | | | | | | | | | | | | | | | | | | | | ]

[ | | | | | | | | | | | | | | | | | | | | ]

Figure 7. Stream Aquatic Habitat Inventory: Stream Identification Form (from Collotzi, 1975).

STREAM AQUATIC HABITAT INVENTORY

(Coded for Computer - Print or Type)

Stream Station Form

Stream ______________________ Forest ______________________

Date ______________________ Investigator ______________________

Photo No. ______________________

1 - Card 2     2 - Catalog No. [ | | | | | | | | | | | | | | ]

3 - State     4 - Forest

| State | Forest | | | |
|---|---|---|---|---|
| ___ California | ___ Ashley | ___ Dixie | ___ Salmon | ___ Wasatch |
| ___ Idaho | ___ Boise | ___ Fishlake | ___ Sawtooth | |
| ___ Nevada | ___ Bridger-Teton | ___ Humboldt | ___ Targhee | |
| ___ Utah | ___ Caribou | ___ Manti-LaSol | ___ Toiyabe | |
| ___ Wyoming | ___ Challis | ___ Payette | ___ Uinta | |

5 - Date of Sample [ | | | ]     6 - Station No. [ | | ]

7 - Location: Longitude [ | | | | | ], Latitude [ | | | ]     8 - Sample No. [ | ]

9 - Gradient [ | | ]     10 - Velocity [ ] [ | ]     11 - Volume, cfs [ | | | | ]

12 - Valley Bottom Width [ | | | ]

13 - Beaver
- [ ] Active beaver dams
- [ ] Inactive or old beaver dams, but in good repair.
- [ ] Inactive or old beaver dams, but in poor repair.
- [ ] Evidence of old beaver dams, but little affect upon stream.
- [ ] No beaver activity present.

14 - State Class [ ]     15 - Fishery [ | | | | ]

16 - Endangered - Threatened Species [ | | ]

17 - Invert. grams/meter sq. [ ]     Div. Index [ ]     18 - Geologic Class [ ]

19 - Geologic Landform

| | Landform | Valley Bottom Material |
|---|---|---|
| [ ] | U-shaped valley | moraine |
| [ ] | U-shaped valley | alluvium |
| [ ] | U-shaped valley | bedrock |
| [ ] | V-shaped and open valley | moraine |
| [ ] | V-shaped and open valley | alluvium |
| [ ] | V-shaped and open valley | bedrock |
| [ ] | Planar landform | moraine |
| [ ] | Planar landform | alluvium |
| [ ] | Planar landform | bedrock |

20 - Access
- [ ] Access is satisfactory for modern car.
- [ ] Access is not too good, but can be reached by car.
- [ ] Access road or trail is fit or appropriate for jeep, horseback, or foot.
- [ ] Access trail for horseback or foot.
- [ ] No trails to area.

21 - Temperature: Air [ | ]     Water [ | ]     22 - Time of Day [ | | | ]

23 - Elevation [ | | | | ]

Figure 8. Stream Aquatic Habitat Inventory: Stream Station Form (from Collotzi, 1975).

Pool Location: 1. right bank
2. left bank
3. center if not bank associated

Pool Feature: 1. boulder
2. overhanging bank
3. water depth
4. vegetation if tree roots
5. log jam
6. beaver dam
7. rock outcrop
8. other

Type - Space 72 1. bedrock
2. sunken log
3. decaying vegetable matter
4. other

Bank Measurements:

Environment 1. Forested
2. Brush
3. Exposed grasses
4. Exposed solid rock or bare soil

Stability 1. Stable
2. Unstable

| Pool Rate | Pool Length or Width | Pool Depth | Pool Shelter* |
|---|---|---|---|
| 1 | Greater than ave. stream width | 2' or deeper | Abundant1/ |
| | Greater than ave. stream width | 3' or deeper | Exposed2/ |
| 2 | Greater than ave. stream width | 2' or deeper | Exposed |
| | Greater than ave. stream width | -2' | Intermediate3/ |
| | Greater than ave. stream width | -2' | Abundant |
| 3 | Equal to ave. stream width | -2' | Intermediate |
| | Equal to ave. stream width | -2' | Abundant |
| 4 | Equal to ave. stream width | Shallow4/ | Exposed |
| | Less than ave. stream width | Shallow | Abundant |
| | Less than ave. stream width | Shallow | Intermediate |
| | Less than ave. stream width | -2' | Intermediate |
| | Less than ave. stream width | +2' | Abundant |
| 5 | Less than ave. stream width | Shallow | Exposed |

*Shelter = Logs, stumps, boulders in or overhanging pool. Dense beds of aquatic vegetation or overhanging banks.
1/Abundant = More than 1/2 perimeter of pool has cover.
2/Exposed = Exposed (little or no shelter or cover) less than 1/4 of pool perimeter has cover.
3/Intermediate = 1/4 to 1/2 perimeter of pool has cover.
4/Shallow = Approximately equal to average stream depth.

| | WATER SURFACE | | | | | | | | | | | | | | | | | STREAM BOTTOM | | | | | | | BANK MEASUREMENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | POOLS | | | | | | | | | | | | | | | | | | | | Left Bank | | Right Bank | |
| | | | | | 1 | | | | 2 | | | | 3 | | | | | | | | | | | | | | | |
| CODE CARD | Channel Width | Water Width | Average Depth 00.0 | Riffle Width | Pool Width | Rating | Location | Feature | Pool Width | Rating | Location | Feature | Pool Width | Rating | Location | Feature | Aquatic Plants | 12+ | 6 - 12 3 - 6 | 1 - 3 1/8 - 1 | Sand | Silt | Type | Other | Envir. | Stability | Envir. | Stability |
| 3 | . . . | . . | . . | . . | . . | | | . | . . | | | . | . . | | | . | . . | . . | . . | . . | . . | . . | | . . | | | | |
| | . . . | . . | . . | . . | . . | | | . | . . | | | . | . . | | | . | . . | . . | . . | . . | . . | . . | | . . | | | | |
| | . . . | . . | . . | . . | . . | | | . | . . | | | . | . . | | | . | . . | . . | . . | . . | . . | . . | | . . | | | | |
| | . . . | . . | . . | . . | . . | | | . | . . | | | . | . . | | | . | . . | . . | . . | . . | . . | . . | | . . | | | | |
| | . . . | . . | . . | . . | . . | | | . | . . | | | . | . . | | | . | . . | . . | . . | . . | . . | . . | | . . | | | | |

COMMENTS ______________________________

Figure 8. (continued)

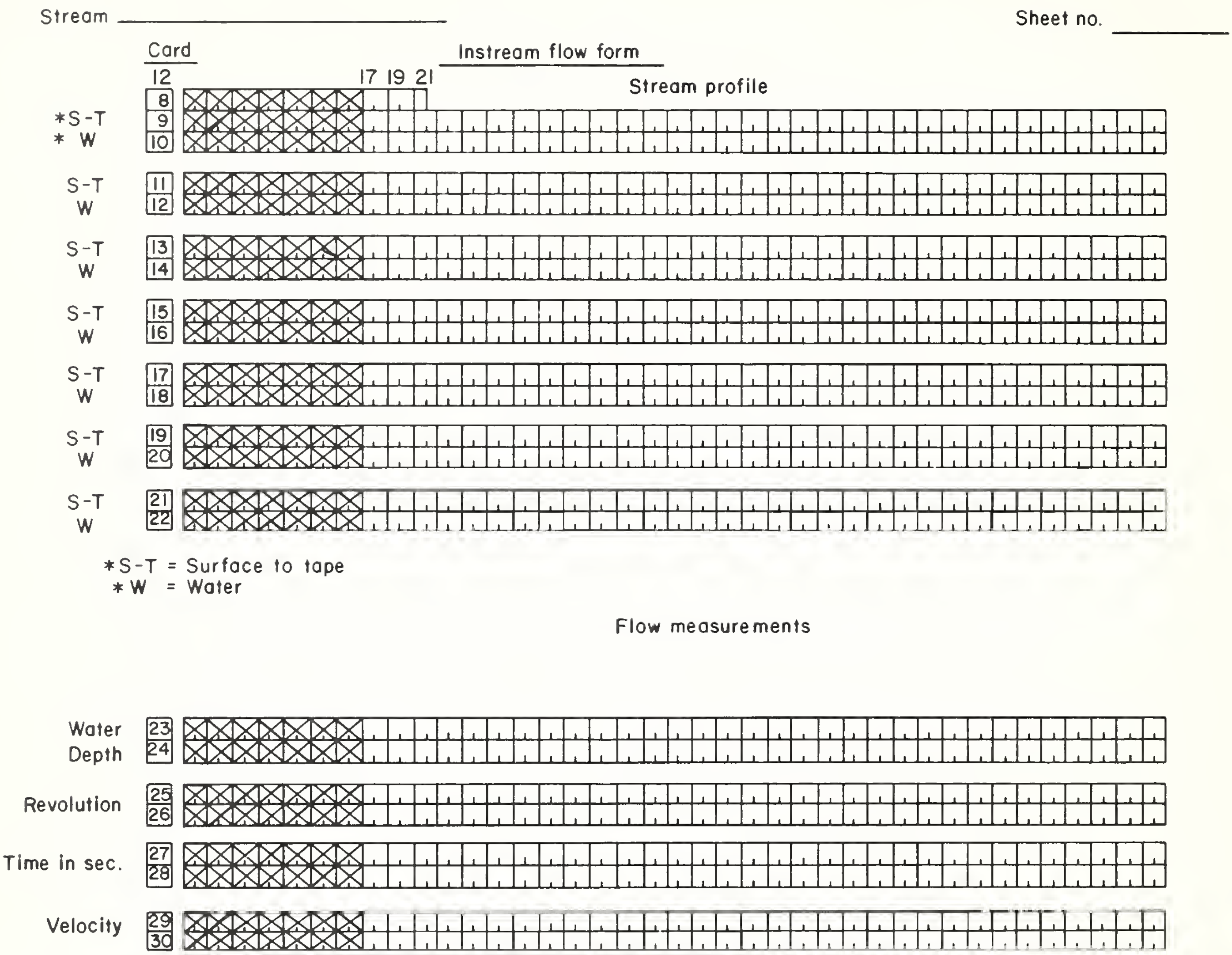



Figure 9. Stream Aquatic Habitat Inventory: Instream Flow Form (from Collotzi, 1975).

Stream Station. The Stream Station Form has been designed for use in the field. Information on this form occupies six cards of 80 spaces each to be used in the computer center. The first card has to do with measurements or observations that are made only once at each station. The remaining five cards are for each of the five transect lines to be measured at the station. The data to be collected along the transects are as described in the manual for stream habitat survey and analysis with a few modifications. The items on this form need to be completed as follows:

Card Code #2.

Item 1 - Card Code. This item requires no entry.

Item 2 - Catalog Number. Same as Item 2 under Stream Identification.

Item 3 - State. Check the appropriate square.

Item 4 - Forest. Check the appropriate square.

Item 5 - Date of Sample. Enter month and year of sample.

Item 6 - Station Number. Enter the station number at left of decimal point. The right space is reserved for nine more stations between each regular station. This allows for greater detailed analysis at the project level. These extra stations would be recorded as 09.1, 09.2, etc. This will require preplanning for every stream prior to sampling.

Item 7 - Location. Give the location of the station as close as possible by longitude and latitude.

Item 8 - Sample Number. The first time a station is sampled the sample number would be 01, the next time it would be 02, etc.

Item 9 - Gradient. Record gradient to the nearest one-half percent.

Item 10 - Velocity. The first space is reserved for number 1 if measured with equipment or number 2 if estimated. The velocity is recorded in the next two spaces.

Item 11 - Volume. Record in cfs to nearest whole number.

Item 12 - Valley Bottom Width. The valley bottom is described as that area of land that has been formed as a result of water-related processes, glacial activity, and may be influenced by the present stream. In many cases it will be from toe slope to toe slope. The measurement is to be made to the nearest 10 feet, excluding the channel width.

Item 13 - Beaver Influence. Check the appropriate square.

Item 14 - State Stream Classification. Most states have given fishery streams a classification based upon the productivity of the stream along with other items such as access and aesthetics. If the classification is available, record it in this space.

Item 15 - Fishery. Starting from the left, record the most dominant or important fish species, using the corresponding letter. Up to five species can be listed.

| | |
|---|---|
| A. Rainbow Trout | N. |
| B. Cutthroat Trout | O. |
| C. Brown Trout | P. |
| D. Brook Trout | Q. |
| E. Lake Trout | R. |
| F. Salmon (Anadromous) | S. |
| G. Salmon (Kokanee) | T. |
| H. Steelhead Trout | U. |
| I. Golden Trout | V. |
| J. Whitefish | W. |
| K. Grayling | X. |
| L. | Y. |
| M. | Z. |

Item 16 - Endangered-Threatened Species. The first space is reserved for the specific classification of the specie. The remaining spaces are reserved for up to two species.

Specific Classification

Federal:

1 - Endangered
2 - Rare

State:

3 - Rare
4 - Peripheral
5 - Endangered
6 - Status Undetermined

Other:

7 - Unique

Species

A - Snake River Cutthroat
B - Colorado River Cutthroat
C - Kendall Warmspring Dace
D -

Item 17 - Invertebrates. Two items are entered on the form. These are weight per cubic meter of organisms and a diversity index. Most streams may not have this information for some time. The data to be collected, analysis work, and entries at Item 17 will be described in water quality surveillance guidelines. Enter the letter which corresponds to your results.

Macroinvertebrate Standing Crop

| Scale: | | $gm/m^3$: |
|---|---|---|
| A=0 | High | 10-15 |
| B=1 | Average | 5-9 |
| C=2 | Low | 0-4 |
| D=3 | | |
| - | | |
| - | | |
| Z=25 | | |

Macroinvertebrate Diversity Index

| | Stream Condition | $SCI_t$ (based upon 40 taxa) |
|---|---|---|
| A=0 | | |
| B=1 | | |
| C=2 | | |
| D=3 | | |
| - | Excellent | 18-30 |
| - | Good | 11-17 |
| - | Fair | 6-10 |
| K=10 | Poor | 0-5 |
| - | | |
| - | | |
| - | | |
| P=15 | | |
| - | | |
| - | | |
| - | | |
| U=20 | | |
| V=22 | | |
| W=24 | | |
| X=26 | | |
| Y=28 | | |
| Z=30 | | |

Item 18 - Geological Classification Developed by Oakes & Glenn. The data for this space is available from the soil scientist, geologist or a good geology map, and can be entered later in the office after the field work is completed. The classification is based on the geologic material above the sample point. In order to use this system, you will need to understand the following definitions:

Granite: Includes all pre-Cambrian rocks--chiefly granite--but also includes metasedimentary rocks (gneiss and schist). Produces coarse sediments.

Hard Sedimentary: Paleozoic rocks. Well consolidated, contains high proportion of hard sandstone, limestone, and dolomite. Not high sediment producers.

Soft Sedimentary: Mesozoic and Cenozoic rocks. Poorly consolidated, high frequency of mass movement. Contains many soft plastic shales. High sediment producers--much suspended sediment.

Flows: (Basalt-rhyolite, etc.) Fine grained igneous rocks occurring in large sheets.

Select the category which best fits the situation and place the letter in the space.

| Primary | Dominant Secondary |
|---|---|
| A-Granite-100% | None (may allow 10% inclusions) |
| B-Granite->50% | Hard Sedimentary <50% |
| C-Granite->50% | Soft Sedimentary <50% |
| D-Granite->50% | Flows (lava, rhyolite, etc.) <50% |

| Primary | Dominant Secondary |
|---|---|
| E-Hard Sedimentary-100% | None (10% inclusions OK) |
| F-Hard Sedimentary->50% | Granite-<50% |
| G-Hard Sedimentary->50% | Soft Sedimentary-<50% |
| H-Hard Sedimentary->50% | Flows-<50% |
| I-Soft Sedimentary-100% | None (10% inclusions OK) |
| J-Soft Sedimentary->50% | Granite-<50% |
| K-Soft Sedimentary->50% | Hard Sedimentary-<50% |
| L-Soft Sedimentary->50% | Flows-<50% |
| M-Flows-100% | None (10% inclusions OK) |
| N-Flows->50% | Granite-<50% |
| O-Flows->50% | Hard Sedimentary-<50% |
| P-Flows->50% | Soft Sedimentary-<50% |

Item 19 - Space 65 - Geology Landform. While at the station, try to determine the geology landform as described. If this becomes difficult, record comments and discuss with a soil scientist or geologist upon returning from the field. Select the process which best describes the situation and check the appropriate square.

Item 20 - Access. Check the appropriate square.

Item 21 - Temperature. Record the air temperature at the time of sampling in degrees Fahrenheit. Record the water temperature at the time of sampling in degrees Fahrenheit.

Item 22 - Time of Day. Record in military time the time of day temperatures are being taken.

Item 23 - Elevation. Can be taken from topographic map or measured with a pocket altimeter.

Card Codes 3 through 7. This section has to do with measurements that are repeated from transect to transect. All measurements are made as described in the manual. Only two major changes have been made from those in the manual. These are the separation of sand and silt measurements and the elimination of Class under bank measurements.

This section is also coded for the computer and where words were used in a space in the past, a number must be used, such as pool location and feature, type of other under stream bottom, and environment and stability under bank measurement. Although these parameters and numbers are listed in this write-up, they are also listed above this section on the Stream form for use in the field.

Unless there is a need for a parameter to be converted to a number it will not be discussed. Parameters will be discussed from left to right.

Average Depth - record to nearest tenth of a foot. Examples: 16.2, 3.0, etc.

Pools - This form allows for up to three pools per transect.

Pool Rating - as described in the procedure for Stream Habitat Analysis.

Pool Location -
1. right bank
2. left bank
3. center if not bank associated

Pool Feature -
1. boulder
2. overhanging bank
3. water depth
4. vegetation if tree roots
5. log jam
6. beaver dam
7. rock outcrop
8. other

Type - this space identifies the stream bottom if classed as "other."
1. bedrock
2. sunken log
3. decaying vegetable matter
4. other

Bank Measurements -

Environment -
1. forested
2. brush
3. exposed grasses
4. exposed solid rock or bare soil

Stability -
1. stable
2. unstable

This form also has a large section for comments to be used as needed.

Card Codes 8 and continued as needed. This section has to do with additional measurements needed to determine instream flow requirements. The Instream Flow Form has been designed for use in the field. If more space is needed for a particular station additional sheets can be used.

Item 1 - Spaces 1 & 2 - Card Code. This item requires no entry.

Item 2 - Spaces 3-16 - Catalog Number. These spaces reserved for catalog number of stream. Item requires no entry.

Item 3 - Card #8 - Spaces 17-20 - Unit of Measure. Spaces 17 and 18 are to be used to record the distance between measurements when completing the stream profile such as 1.0 (1 foot), 1.5 (1.5 feet), etc. Spaces 19 and 20 are to be used to record the distance between flow measurements such as 1.0 (1 foot), 2.5 (2.5 feet), etc.

Item 4 - Card #8 - Space 21 - Additional Sheets. This space is to be marked only if additional sheets are to be used. List sheets such as 2, 3, etc.

Item 5 - Cards 9-22 - Stream Profile. Each pair of card codes is used at the same time, such as 9 and 10. The measurement of the surface to tape is recorded in the upper card in tenths of feet and the water depth in tenths of feet in the lower card. Measurements are made from the left bank to the right bank.

Item 6 - Cards 23-30 - Flow Measurements. The first two cards (23 and 24) are to record water depth at point of measurement in tenths of feet. Cards 25 and 26 are to record revolutions at each point of measurement. Record time in seconds on cards 27 and 28 for the number of revolutions. Cards 29 and 30 are to be used when using a direct reading current meter. Record to the nearest tenth such as 1.3, 2.3, etc. All measurements are made from the left bank to the right bank."

Habitat Rating

Dunham and Collotzi (1975) present the following habitat rating procedure for each sample station, based upon the field data collected following the techniques outlined above (Table 3 summarizes the habitat analysis for one sample station).

Habitat for each sample is rated in the four categories of pool measure, pool structure, streambottom and stream environment which leads to the final habitat percent of optimum. All ratings use a numerical score system.

Pool Measure - a rating of the total sample width in cover elements of pool and riffle.

When pool width is 50 percent of total width, rating is 100 percent.

When pool width, p, is less than 50%, solve: $100-[(p-50)x2] = \%$ rating.

When pool width, p, is greater than 50%, solve: $100-[(p-50)x2] = \%$ rating.

Pool Structure - a rating of pool quality:

$$\text{Percent Rating of Pool Measure} \times \frac{\text{Total feet of 1, 2, 3 rated pools}}{\text{Total feet in pools}} \times 100 = \text{Percent Rating of Pool Structure}$$

Streambottom - percent of total sample width over gravel and rubble bottom.

$$\frac{\text{Ft gravel + ft rubble}}{\text{Total feet in streambottom sample}} \times 100 = \text{Percent Rating of Streambottom}$$

Stream Environment - a rating of streambank vegetative cover in order of tree, brush, grass and exposed.

Count for each bank point as follows:

Tree = 4 points
Brush = 3 points

Add the points for bank environment observations to obtain a total for the sample. Then proceed as follows:

$$\frac{\text{Total pts for observs.}}{\text{Maximum possible pts if all observs. were recorded as tree}} \times 100 = \text{Percent Rating of Stream Environment}$$

Habitat Percent of Optimum -

$$\frac{\text{Pool measure + pool structure + streambottom + stream environ.}}{400} = \text{Habitat Percent of Optimum}$$

Table 3. Habitat analysis for one sample station (from Dunham and Collotzi, 1975).

| | |
|---|---|
| Sample Number | 1 |
| Total Lineal Feet | 65 |
| Percent Bank Stability | 90 |
| Pool | |
| Location | |
| Bank | 3 |
| Entire | 15 |
| Center | 8 |
| Cover Feature | |
| Vegetation | 18 |
| Depth | 8 |
| Boulder | 0 |
| Rating | |
| 1, 2, 3 | 26 |
| 4, 5 | 0 |
| Habitat Analysis | |
| Pool Measure | 80 |
| Pool Structure | 80 |
| Streambottom | 45 |
| Stream Environment | 70 |
| Percent of Optimum | 69 |

Instream Flow Determination (from Dunham and Collotzi, 1975)

From the index flow transect data, field measured values have been obtained for water surface width, wetted perimeter, maximum depth, velocity and habitat rating value. Also, using the depth measurements, the cross section can be plotted (Figure 10). As the sag- or tight-tape techniques have been used to collect these transect data, the R-2 Cross program or hand calculation using Manning's equation,

$$(V = \frac{1.486}{n} \times R^{2/3} \times S^{1/2}) ,$$

can be used to compute estimates of flow ($Q = A \times V$) at additional water stages. Examples of such synthesized data are shown in Figure 10 and Table 4. Also estimates of the habitat rating values at the computed water stages should be made, based upon these synthesized data and the rating system described above.

The investigator now has before him the results of the habitat survey and analysis, the index discharge, a channel profile tracing, and a tabulation of hydraulic geometry and discharge at several water levels. It remains to interpret the relationship among and between the several hydraulic variables and to estimate the habitat retention using percentage increments at the several discharges, and to show the data points on graphs, as in Figures 11 and 12, to display the habitat.

Two habitat trend lines, labeled A and B, are drawn on the graph of Figure 12. These lines represent two stream habitats, and they are the average condition for several cross sections along the two stream courses. Such averaging may be done where there is little or no gain or loss in streamflow along the channel. The field measured habitat value is assigned 100 percent and is the point on each line at the graph's upper right-hand corner. For line A, at 50 percent of discharge, habitat is estimated as equal to 90 percent of the field measured value. For line B, at 50 percent of discharge, habitat is estimated as equal to 85 percent of the field measured value.

The estimated minimum flows for habitat lines A and B are 50 and 40 percent of discharge, respectively. These were determined as follows.

For line A, the estimated habitat value ranges between 90 and 100 percent of field measured value for discharges between 50 and 100 percent. At 40 percent of discharge, habitat is estimated at 80 percent of field measured value, and at 30 percent of discharge habitat is estimated at 70 percent of field measured value. Therefore, the absolute minimum flow is at 50 percent of discharge, equal to 90 percent of habitat value because of the sharp fall-off in value after the 90 percent value.

Line B has uniform slope between 80 and 100 percent of field measured habitat value. Therefore, the most desirable minimum flow is at 40 percent of discharge, equal to 80 percent of habitat value. Discharge equal to 80

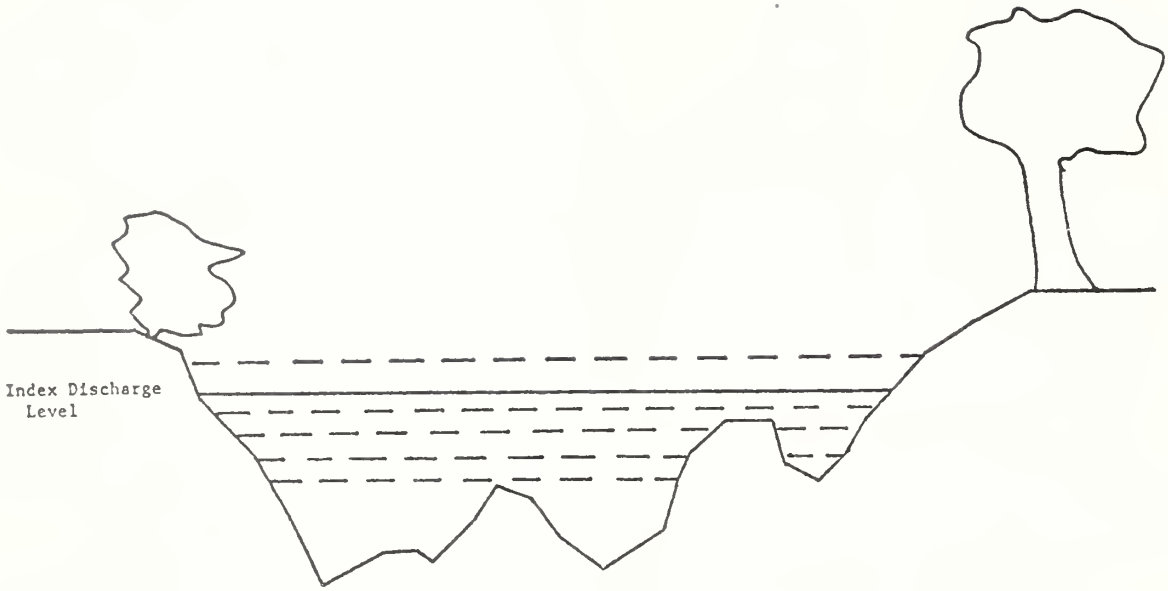



Figure 10. A profile.

Table 4. Tabulation of cross section data (from Dunham and Collotzi, 1975).

| Sample Number | Water Level Number | Wetted Perim. | Surf. Width | Max. Depth | Cross Sec. Area | Slope | Manning's Formula N Factor | r 2/3 | S 1/2 | Vel. of Flow | Dis- charge | Percent Habitat Reten. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 12.5 | 12.0 | 1.425 | 10.13 | .014 | .102 | .869 | .1183 | 1.5 | 15.2 | 100 |
| | 2 | 11.3 | 10.9 | 1.225 | 7.83 | " | " | .784 | " | 1.4 | 11.0 | 100 |
| | 3 | 10.0 | 9.6 | 1.025 | 5.81 | " | " | .696 | " | 1.2 | 7.0 | 75 |
| | 4 | 8.8 | 8.5 | 0.825 | 4.07 | " | " | .597 | " | 1.0 | 4.1 | 75 |
| | 5 | 6.7 | 6.5 | 0.625 | 2.32 | " | " | .493 | " | .9 | 2.1 | 50 |
| | 6 | 5.5 | 5.5 | 0.425 | 1.33 | " | " | .388 | " | .7 | .9 | 25 |

percent of field measured habitat value was considered the lowest acceptable rate of flow, although final determination also took into account the rate of change in habitat for percentage units of discharge.

### USFS Region 1 Method
### (Cooper, 1976; and Isaacson, 1976)

The Region 1 Stream Survey procedure is similar to the methodology developed by Dunham and Collotzi (1975) and Chrostowski (1972) for USFS Region 4 (see R-4 Method, above) except that it is broken into two levels of assessment and more importantly in the context of this report, is not explicitly designed to determine instream flow needs. For this latter reason a more detailed discussion of the procedure is not presented here. Level I is employed on streams "directly affected by an activity which may require habitat monitoring or a reasonably accurate assessment of aquatic habitat" (R-4 Method); Level II employs a survey on streams which do not require monitoring or statisti-

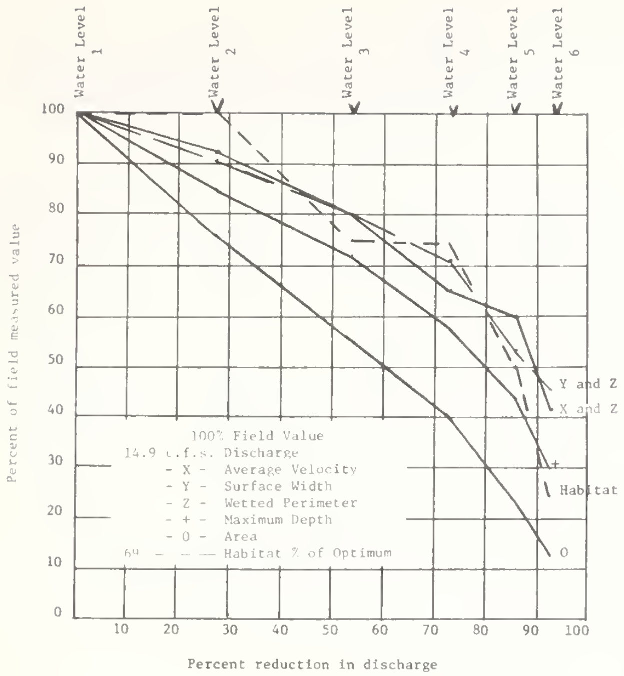



Figure 11. Selected hydraulic variables at representative cross sections.

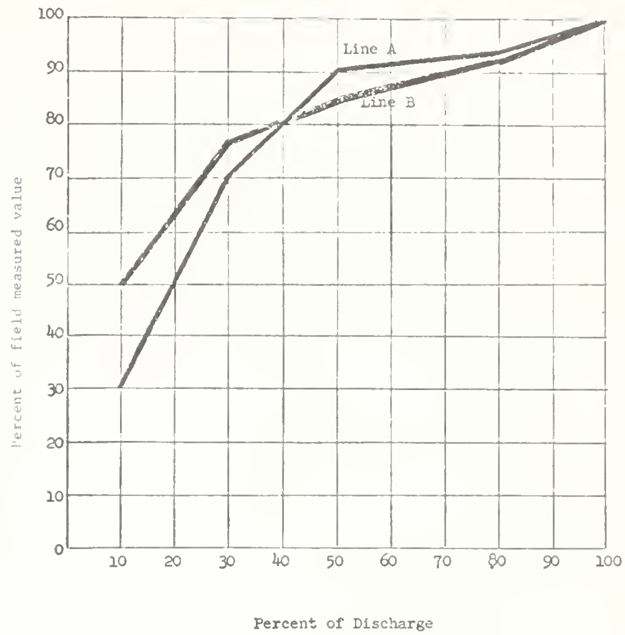



Figure 12. Estimation of minimum flow by the graphic representation of habitat data.

cally reliable figures. Level II surveys are primarily ocular.

For instream flow determinations, Region I uses the Region 2-Cross method.

### Waters Method (Waters, 1976a)

This methodology, like those of Collings and Swank, arrives at an optimum flow for specific activities of various species. This is not to be confused, however, with a "minimum flow and should not be recommended as such.

Described below are the steps, materials, techniques, and analytical methods followed in a typical streamflow study using the method from Waters (1976a).

#### Preliminary Planning and Field Work Preparation

"Representatives of all organizations cooperating in the study meet to agree on which section(s) of stream will be studied, which release flows will be studied, how release flows will be verified, when the study will occur, the number and locations of stations and transects, the spacing of measuring points along each transect, the identity of individual field workers, the location of photographic stations and other related matters. It is agreed that each cooperating organization will receive a copy of all original field data sheets with which to do anything it wishes, independently of an agreement to share results of the analysis resulting from the computer program described later in this paper.

"On some streams a preliminary field review is undertaken to observe typical sections under several flows. These observations, possibly documented by photography, may then be used as a basis for selecting study stations and release flows.

"If more than one crew of workers will be involved in the data collection, an attempt is made during the planning phase to balance the capabilities of each crew after considering such

factors as employer organization, experience on studies of this type, logistic support (if it covers a large geographic area), and which days people are available. For continuity, it is desirable to have the same personnel available for all days of the study. In particular, if cover is included as a study parameter, it is imperative that the same worker conduct the subjective evaluation each day.

"The number of stations per stream section, the number of transects per station, and the distance between measuring points along each transect will depend on the variability in stream type (cascades, runs, riffles, pools) and mean stream width. Based on past experience with stream habitat variability and practical logistics problems, around 600 measuring points per stream section are generally selected. A three-person crew with one meter should be able to collect at least 300 point measurements per day, and a five or six-person crew with two meters should be able to collect at least 600 point measurements per day. These work budget figures include consideration of average travel time, normal accessibility, and a normal workday. Table [5] gives guidance as to the number of measuring points which various combinations of stream width, measurement interval along transects, and total number of transects would indicate.

"Station locations are selected to be representative of the stream section in question. Major pool areas are avoided because they are not habitats where significant ecological changes occur with changes in flow. However, if resting habitat is likely to be a limiting factor, slow water areas may be given special consideration. Ease of access is a consideration in station location selection only when the representativeness of the final locations selected is assured. If uncontrolled accretion is significant in a stream section, stations should be spaced to include the range of accretion flow conditions that exist.

"After station locations and the number of transects per station have been determined, the ends of transects are identified with stakes firmly installed above the water line of the highest flow studied. The distance between transects (commonly 20 to 50 feet) depends mostly on the length of stream available at the station. Stakes are located on one side of the stream by measuring the fixed, predetermined interval along the streambank. Stake locations for the ends of the transects on the opposite streambank are selected by eye such that the transect is perpendicular to the flow at that point in the stream even if this results in adjacent transects not being parallel.

Table 5. Number of measuring points resulting from various combinations of stream width, measurement interval along transects, and total number of transects.

| If mean stream width at highest test flow is (ft): | And measurements are taken at intervals of (ft): | At a total number of transects of: | The number of measuring points will be: |
|---|---|---|---|
| 0-15 | 0.5 | 18 | 0-540 |
| 16-20 | 0.5 | 12 | 380-480 |
| 21-30 | 1.0 | 18 | 380-540 |
| 31-40 | 1.0 | 12 | 360-480 |
| 41-50 | 2.0 | 18 | 370-450 |
| 51-75 | 2.0 | 15 | 380-560 |
| 76-100 | 4.0 | 18 | 340-450 |
| 101-150 | 5.0 | 15 | 300-450 |
| 151-200 | 5.0 | 12 | 360-480 |
| 201-300 | 10.0 | 15 | 300-450 |

Note: Transects are divided evenly between stations, usually two or three stations.

Source: Waters, 1976a.

### Field Data Collection

"Prior to the initiation of field measurements, all participants should meet to review individual responsibilities, resolve any questions, stress the importance of a standard systematic approach to all aspects of the field study, and inventory equipment and review its use.

"A typical equipment list, which would be duplicated with multiple crews, includes the following: (1) [pygmy current] meter(s) with spare parts, (2) measuring tapes (nonstretchable), (3) stop watches, (4) extra transect stakes, (5) data recording forms, (6) clipboard(s), (7) pencils, (8) tape clamps and/or pullers, (9) chalk board, (10) chalk, (11) thermometer, (12) plastic flagging tape, (13) maps, (14) camera and color film, (15) first aid kit, (16) snake bite kit, (17) rope, (18) suntan lotion, and (19) felt soled shoes. [Current] meters should be calibrated before and after the study to assure that the calibration did not change.

"An example of the field data recording form is given in [Figure 13], and the general instructions for using it are given in Table [6].

PLEASE PRINT CLEARLY

Page ____ of ____

Notes:

| Stream | | | | | | | | | | | | Sta No | | Tr No | | Depth of Meas | | | Date | | | | | | Time | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | Mo | | Day | | Yr | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
| | | | | | | | | | | | | | | | | | . | | | | | | | | | | | |

| Water Temp F | | | | Test Flow | | | | | Meter No | | | | | | | Measured by | | | | | | | Recorded by | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 |
| | | . | | | | | . | | | | | | | | | | | | | | | | | | | | | | |

| Distance on Transect | | | | | Btm Code | | Cvr Code | | Depth in feet | | | | Revo-lutions | | | Time in Seconds | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 |
| | | | . | | | | | | | | . | | | | | | | | . | |
| | | | . | | | | | | | | . | | | | | | | | . | |
| | | | | | | | | | | | . | | | | | | | | . | |
| | | | . | | | | | | | | . | | | | | | | | . | |


| Distance on Transect | | | | | Btm Code | | Cvr Code | | Depth in feet | | | | Revo-lutions | | | Time in Seconds | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 |
| | | | . | | | | | | | | . | | | | | | | | . | |
| | | | | | | | | | | | . | | | | | | | | . | |
| | | | . | | | | | | | | . | | | | | | | | . | |
| | | | . | | | | | | | | . | | | | | | | | . | |


Bottom Type Code:

1 Plant Detritis
2 Clay
3 Silt
4 Sand
5 Gravel (1/8" - 3")
6 Rubble (3" - 12")
7 Boulder (>12")
8 Bedrock
9 Other

Subjective Cover Code:

1 No Cover
2 Fair Cover
3 Good Cover

PLEASE PRINT CLEARLY

Figure 13. Example of streamflow evaluation field data recording form (from Waters, 1976a).

Table 6. Instructions for filling out streamflow evaluation data recording form (from Waters, 1976a).

---

Note: Always print clearly with medium soft pencil (No. 2 or 2-1/2).

| Columns | Recorded Information |
|---|---|
| 1-12 | Name of stream. Be as specific as possible as to location. Use AB=Above, BL=Below. Use abbreviations when necessary (e.g., NFKINGSABWIS = North Fork Kings River above Wishon). |
| 13-14 | Station number in the section of stream being tested, 1-99. |
| 15-16 | Transect number at the station, 1-99. |
| 17-19 | Depth of measurement. Usually held constant at 0.2 feet. |
| 20-25 | Date. Use normal sequence of month, day, year. |
| 26-29 | Time. Military time approximately half way through transect. |
| 30-33 | Water temperature in °F to nearest 0.1° if taken. |

Table 6. (continued)

| | |
|---|---|
| 34-38 | Test flow in cfs to nearest 0.1 cfs. This is the release flow that exists at the time of the study. Do not record intended test flow. Record only after actual release flow is verified. |
| 39-45 | Meter No. (right and adjusted). If more than seven alpha-numeric characters long, use last seven. |
| 46-52 | Measured By (left adjusted). Name of person who does all or majority of metering. Use sequence of first initial, second initial, last name. If more than five letters in last name, record only the first five. |
| 53-59 | Recorded By (left adjusted). Same instructions as Measured By. |
| 60-64 | Distance on Transect. The point along the tape in feet where the measurement is taken. Skip all dry areas that occur at the first (highest) flow. |
| 65-66 | Bottom code (right adjusted) using the key at the bottom of the recording form. This only has to be recorded once, and is done at the lowest test flow for convenience in evaluating substrate type. It has to be recorded for all points at which any measurements are taken on any day of the study, even if that point is dry on the day it is recorded. |
| 67-68 | Subjective cover code (right adjusted) using the key at the bottom of the recording form. Recorded only if this option is to be included in the study. |
| 69-72 | Total water depth to nearest 0.1 feet at point of measurement. If substrate is dry at the point on that day, record as 0. |
| 73-75 | The number of complete revolutions counted after the revolution noted when the stopwatch started. Flow meter is set at depth indicated in Columns 17-19. Epic counter may be used. |
| 76-80 | Elapsed time to the nearest 0.1 second (minimum of 30 seconds) from when stopwatch started until it is stopped at a completed revolution of the flow meter. Record as 30 seconds if no depth or too shallow to get a velocity (revolutions) reading. Epic counter may be used. |

"Upon arriving at a transect, crew members stretch the tape tightly between the two stakes. At this point, it is especially important to have the zero end of the tape exactly over the base of the stake. The zero has to be at the same place for each study flow. The zero end of the tape is always on the study access side of the stream.

"The highest flow to be studied is released first, immediately confirming that transect stakes have been placed appropriately in relation to water elevation. Study participants are then able to fill in columns 60-64 of the field data recording forms (distance on transect) in advance for all subsequent (lower) flows to assure that all required depth, velocity, and substrate data are collected. Actual release flows are verified, as well as the actual flows existing at the stations (release plus accretion). Flows are allowed to stabilize before any measurements are made. Usually this is done by having only one study flow per day, with releases set late in the afternoon of the previous day. On uncontrolled streams, study participants must attempt to obtain differing flows as they occur naturally, even if this requires long time periods between field study days.

"Velocity measurements for these salmonid stream studies are taken at 0.2 feet above the substrate. The data analysis takes this into account to the extent possible. Substrate type (bottom code) is recorded as that which best typifies the substrate at the given point along the transect and is recorded at the lowest flow.

"Each day of the study, photographs are taken in a standardized fashion at each station. The photographs are scheduled to be taken as close to the same time of the day at each of the stations each day so that lighting and shade conditions are comparable. Usually three photographs are taken at each station each day: one directed upstream, one directed across the stream, and one directed downstream. The station number, date, and intended release flow are recorded on a slate placed within view of each photograph for ease

of identification. The photographs are later presented so that all [those] taken looking in a particular direction at a given station may be viewed at the same time (e.g., on facing pages) for ease of comparison. Accompanying each photograph is a label which lists the station number, actual release flow, the flow being viewed at the station (release plus accretion), the direction of the view, and the date.

Data Processing

"Field data are keypunched and verified prior to analysis by computer. A computer program has been developed which calculates the velocity at each measuring point for each study flow, and stores bottom substrate and depth data. As described below, it then calculates a relative value between zero and one for each measuring point along each transect at each station for each study flow and habitat parameter. The habitat parameters are resting microhabitat, food production, spawning, and subjective cover. Subjective cover is optional and may not be included if the researchers want to look only at the other three quantitatively determined habitat parameters.

"The relative values for each measuring point for each parameter at each flow are determined by assigning weighting factors (coefficients in the model) to the individual water velocity, bottom substrate, and depth values, and then multiplying them together to get a single composite relative value. Weighting factors can be varied as a function of the species of fish of concern in the stream, its life history stage, and those of its principal food organisms. The distribution of weighting factors for a typical analysis of the three quantitative habitat parameters in a California trout stream are shown in Figure [14]. Weighting factors for subjective cover are 0.0 for no cover, 0.5 for fair cover, and 1.0 for good cover. [Examples of weighting factors for rainbow trout are shown in Tables 7, 8, and 9.]

"The original determination of weighting factors to be used in our analyses was based on review (Hooper, 1973) of all available sources of information which related physical characteristics (substrate, velocity, and depth) of trout habitat to habitat parameters (resting, food production, and spawning). Steps to determine weighting factors for a particular stream and its biota (some of which may require new research) [are given in detail in Waters, 1976a].

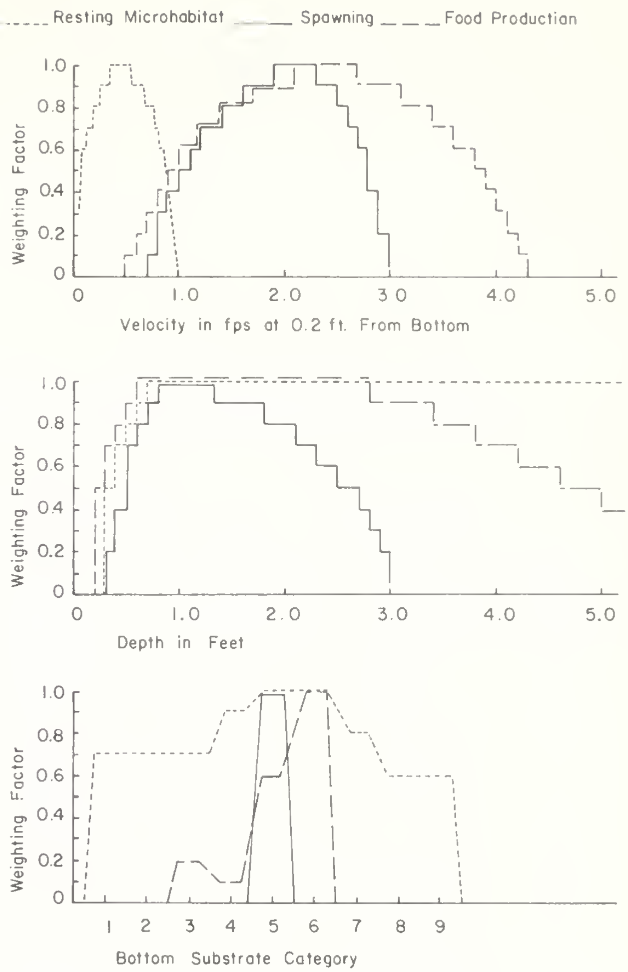



Figure 14. Weighting factors for habitat parameters in a typical trout stream flow analysis (from Waters, 1976a).

"The computer program, which is written in PL/I and used on an IBM 370, Model 168 with Calcomp plotter support, provides the following data in tabulated form for each habitat parameter for each stream studied:

1. Total relative units for each series of transects within each station, including a station total.

2. Total relative units for each series of stations within the stream section under study, including a stream section total.

3. Tables from 1 and 2 in mean relative units.

Table 7. Resting microhabitat criteria and weighting factors, Rainbow Trout (Salmo gairdneri), Pit River, California. Unpublished data, 1975, Brian Waters, Pacific Gas and Electric Co.

| Velocity (0.2' from bottom) | | | Depth (0.2' from bottom) | | | Substrate | |
|---|---|---|---|---|---|---|---|
| Range (cm/sec) | Range (ft/sec) | Weighting Factor | Range (m) | Range (ft) | Weighting Factor | Type | Weighting Factor |
| 0.0-0.6 | 0.00-0.02 | 0.3 | 0.00-0.09 | 0.00-0.29 | none | Rubble | 1.0 |
| 0.9-1.2 | 0.03-0.04 | 0.4 | 0.09-0.12 | 0.30-0.39 | 0.5 | Gravel | 1.0 |
| 1.5-2.4 | 0.05-0.08 | 0.5 | 0.12-0.15 | 0.40-0.49 | 0.7 | Sand | 0.9 |
| 2.7-3.7 | 0.09-0.12 | 0.6 | 0.15-0.18 | 0.50-0.59 | 0.8 | Boulder | 0.8 |
| 4.0-5.5 | 0.13-0.18 | 0.7 | 0.18-0.21 | 0.60-0.69 | 0.9 | Silt | 0.6 |
| 5.8-7.9 | 0.19-0.26 | 0.8 | 0.21 → | 0.70 → | 1.0 | Bedrock | none |
| 8.2-11.0 | 0.27-0.36 | 0.9 | | | | | |
| 11.3-16.5 | 0.37-0.54 | 1.0 | | | | | |
| 16.8-20.1 | 0.55-0.66 | 0.9 | | | | | |
| 20.4-22.6 | 0.67-0.74 | 0.8 | | | | | |
| 22.9-24.4 | 0.75-0.80 | 0.7 | | | | | |
| 24.7-26.2 | 0.81-0.86 | 0.6 | | | | | |
| 26.5-27.4 | 0.87-0.90 | 0.5 | | | | | |
| 27.7-28.3 | 0.91-0.93 | 0.4 | | | | | |
| 28.7-29.3 | 0.94-0.96 | 0.3 | | | | | |
| 29.6-29.9 | 0.97-0.98 | 0.2 | | | | | |
| 30.2-30.5 | 0.99-1.00 | 0.1 | | | | | |
| 30.8 → | 1.01 → | none | | | | | |

Table 8. Spawning criteria and weighting factors, Rainbow Trout (Salmo gairdneri), Pit River, California. Unpublished data, 1975, Brian Waters, Pacific Gas and Electric Co.

| Velocity (0.2' from bottom) | | | Velocity (0.2' from bottom) | | | Substrate | |
|---|---|---|---|---|---|---|---|
| Range (cm/sec) | Range (ft/sec) | Weighting Factor | Range (m) | Range (ft) | Weighting Factor | Type | Weighting Factor |
| 0.0-21.0 | 0.00-0.69 | none | 0.00-0.09 | 0.00-0.29 | none | Gravel | 1.0 |
| 21.3-24.1 | 0.70-0.79 | 0.1 | 0.09-0.12 | 0.30-0.39 | 0.2 | Others | none |
| 24.4-27.1 | 0.80-0.89 | 0.3 | 0.12-0.15 | 0.40-0.49 | 0.4 | | |
| 27.4-30.2 | 0.90-0.99 | 0.4 | 0.15-0.18 | 0.50-0.59 | 0.7 | | |
| 30.5-33.2 | 1.00-1.09 | 0.5 | 0.18-0.21 | 0.60-0.69 | 0.8 | | |
| 33.5-36.3 | 1.10-1.19 | 0.6 | 0.21-0.24 | 0.70-0.79 | 0.9 | | |
| 36.6-42.4 | 1.20-1.39 | 0.7 | 0.24-0.39 | 0.80-1.29 | 1.0 | | |
| 42.7-48.5 | 1.40-1.59 | 0.8 | 0.40-0.55 | 1.30-1.79 | 0.9 | | |
| 48.8-57.6 | 1.60-1.89 | 0.9 | 0.55-0.64 | 1.80-2.09 | 0.8 | | |
| 57.9-69.8 | 1.90-2.29 | 1.0 | 0.64-0.70 | 2.10-2.29 | 0.7 | | |
| 70.1-75.9 | 2.30-2.49 | 0.9 | 0.70-0.76 | 2.30-2.49 | 0.6 | | |
| 76.2-78.9 | 2.50-2.59 | 0.8 | 0.76-0.82 | 2.50-2.69 | 0.5 | | |
| 79.2-82.0 | 2.60-2.69 | 0.7 | 0.82-0.85 | 2.70-2.79 | 0.4 | | |
| 82.3-85.0 | 2.70-2.79 | 0.6 | 0.85-0.88 | 2.80-2.89 | 0.3 | | |
| 85.3-88.1 | 2.80-2.89 | 0.4 | 0.88-0.91 | 2.90-3.00 | 0.2 | | |
| 88.4-91.4 | 2.90-3.00 | 0.2 | 0.92 → | 3.01 → | none | | |
| 91.7 → | 3.01 → | none | | | | | |

Table 9. Food producing criteria and weighting factors, Raonbow Trout (Salmo gairdneri), Pit River, California. Unpublished data, 1975, Brian Waters, Pacific Gas and Electric Co.

| Velocity (0.2' from bottom) | | | Velocity (0.2' from bottom) | | | Substrate | | | |
|---|---|---|---|---|---|---|---|---|---|
| Range (cm/sec) | Range (ft/sec) | Weighting Factor | Range (m) | Range (ft) | Weighting Factor | Type | cm | in | Weighting Factor |
| 15.2-18.0 | 0.50-0.59 | 0.1 | 0.06-0.09 | 0.20-0.29 | 0.5 | Rubble | 7.6-30.5 | 3.0-12.0 | 1.0 |
| 18.3-21.0 | 0.60-0.69 | 0.2 | 0.09-0.12 | 0.30-0.39 | 0.7 | Gravel | 0.3-7.6 | 1/8"-3.0" | |
| 21.3-24.1 | 0.70-0.79 | 0.3 | 0.12-0.15 | 0.40-0.49 | 0.8 | Silt | | | |
| 24.4-27.1 | 0.80-0.89 | 0.4 | 0.15-0.18 | 0.50-0.59 | 0.9 | Sand | | | |
| 27.4-30.2 | 0.90-0.99 | 0.5 | 0.18-0.85 | 0.60-2.79 | 1.0 | | | | |
| 30.5-36.3 | 1.00-1.19 | 0.6 | 0.85-1.03 | 2.80-3.39 | 0.9 | | | | |
| 36.6-42.4 | 1.20-1.39 | 0.7 | 1.03-1.16 | 3.40-3.79 | 0.8 | | | | |
| 42.7-51.5 | 1.40-1.69 | 0.8 | 1.16-1.28 | 3.80-4.19 | 0.7 | | | | |
| 51.8-63.7 | 1.70-2.09 | 0.9 | 1.28-1.40 | 4.20-4.59 | 0.6 | | | | |
| 64.0-82.0 | 2.10-2.69 | 1.0 | 1.40-1.52 | 4.60-4.99 | 0.5 | | | | |
| 82.3-94.2 | 2.70-3.09 | 0.9 | 1.52 | 5.00 → | 0.4 | | | | |
| 94.5-103.3 | 3.10-3.39 | 0.8 | | | | | | | |
| 103.6-109.4 | 3.40-3.59 | 0.7 | | | | | | | |
| 109.7-115.5 | 3.60-3.79 | 0.6 | | | | | | | |
| 115.8-118.6 | 3.80-3.89 | 0.5 | | | | | | | |
| 118.9-121.6 | 3.90-3.99 | 0.4 | | | | | | | |
| 121.9-124.7 | 4.00-4.09 | 0.3 | | | | | | | |
| 125.0-127.7 | 4.10-4.19 | 0.2 | | | | | | | |
| 128.0-131.1 | 4.20-4.30 | 0.1 | | | | | | | |
| 131.4 | 4.31 | none | | | | | | | |

4. Standard deviation of values in tables from 3.

5. 90 percent confidence limits of values in tables from 3.

6. Relative distribution of different categories of bottom substrates.

"The program can also provide results in plot form, an example of which is given in Figure [15]. This can be provided for each habitat parameter by station, and for all stations combined in the stream section under study. These plotted results are the most usable product of the program in that they show the relationship between the magnitude of the habitat parameter of interest (as a dependent variable) and release flow (as the independent variable). The plots provide a tool that biologists and others can use when evaluating the potential effects of different release flows below impoundments. . . .

"Plotting results with only relative units on the vertical scale should suffice if there is only one section of one stream involved in an evaluation, since knowledge of relative changes is all that is probably desired. In order to compare values from one stream to another, or from two or more sections of the same stream, the mean relative units can be multiplied in the program by actual streambed area included in the study to get the equivalent number of optimum quality

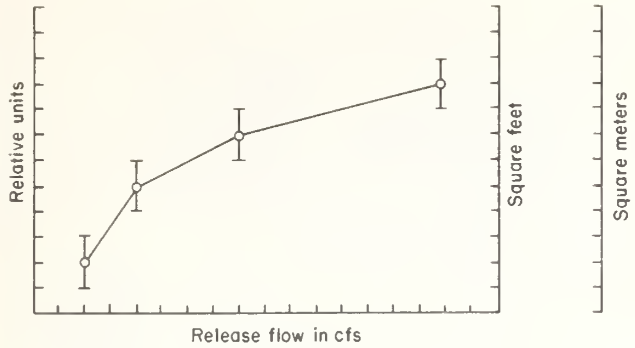



Figure 15. Representative example of plot showing relationship between relative units of habitat parameter and release flow. Ninety percent confidence intervals are shown (from Waters, 1976a).

$ft^2$ (or $m^2$) of the habitat parameter for each, as shown on the area unit scales.

"The program utilizes control cards to enable the user to specify the following (existing limits are shown in parentheses):

1. Name of stream section under study.

2. Number of stations (3 per stream section).

3. Number of transects per station (9).

4. Measurement interval along transects (100 measurements per transect).

5. Length in feet of stream section under study.

6. Percentage of stream length under study that is represented by the study (from aerial photographs or field reconnaissance if area unit scales are desired on the plots).

7. Number of study flows (5).

8. Whether or not subjective cover is included in the study.

9. Whether or not relative unit plots are desired.

10. Whether or not area unit plots are desired.

"The weighting factors are accessed from a file at the time of program and data submittal to the computer."

## Washington Method
## (Collings, 1972 and 1974)

The Washington Method gives "preferred" discharges for spawning by overlying map isohyets of depth and velocity to determine the area of the study reach preferred by salmon for spawning. Then, by plotting square feet of spawnable area versus discharge in cfs, a curve can be developed, the peak of which is designated "preferred spawning discharge." A recommended minimum spawning flow, according to this methodology, is defined as not less than 75 percent of the preferred spawning discharge.

Rearing discharges are determined on the premise that in typical channels, wetted perimeter increases rapidly with discharge to a point where the channel begins to widen. The quantity of water preferred by salmon for rearing is somewhere near this inflection point, i.e., where large changes in discharge begin to bring about only small changes in wetted perimeter.

Equipment list includes the following: (1) transect stakes and hammer, (2) tape measure, (3) depth rod, (4) waders, (5) current meter, (6) data forms, and (7) stop watch.

Field techniques for the Washington Method are as follows (summarized from Collings, 1974):

1. Select at least three study reaches to obtain a good representation of the river and to evaluate the variation of discharges within a stream, as well as between different streams. Reach selection is based upon observed spawning activity and channel stability. The reaches are usually about twice as long as they are wide and extend from a pool over a riffle.

2. If one is not already available, a large-scale, detailed surface map of each reach must be made. This can be done by standard surveying techniques.

3. Four cross section transects are established across each reach about equal distances apart. The stage at which the stream first overflows its banks is termed bankfull stage and is used as the width of the study reach.

4. Stream discharge is measured and water depths and velocities are measured at some 10 to 25 points along each of the four transects. Also, various random depths and velocities are measured at points between the transects in order to more accurately determine the lines of equal depth and velocity. These measurements are taken at a number, usually 10, of different discharges.

Office methods are as follows:

1. Draw two detailed maps of the study reach and plot the depth and velocity data from transects and random points on the maps. By connecting the points of equal depth and velocity, isohyetal maps, like those shown in Figure 16 can be developed for each reach. By overlying one map over the other, the portions of the reach which meet species preferred spawning depth and velocity requirements can easily be outlined, as in Figure 17.

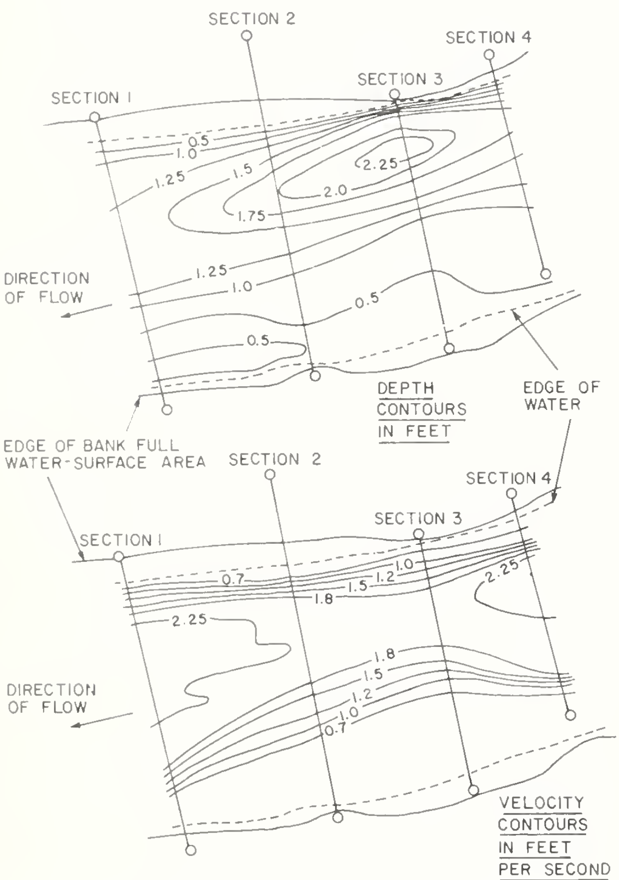



Figure 16. Example of study reach water depth and water velocity contouring for one river discharge, North Nemah River (from Collings, 1972).

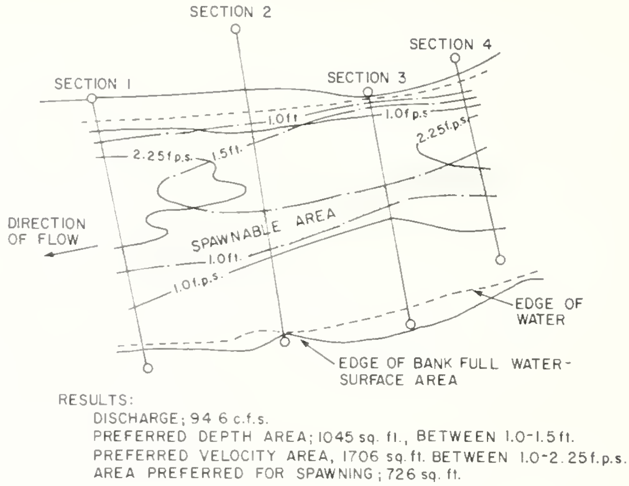



Figure 17. Example of method for determining area of study reach that is preferred for spawning by fall chinook salmon at one river discharge, North Nemah River (from Collings, 1972).

2. Draw these maps for each different discharge measured and determine spawnable area present at each discharge. Then, plot spawnable area versus discharge for each species of interest to get parabolic curves like those shown in heavy black lines in Figure 18. The peak of the curve is the discharge at which the greatest spawnable area occurs (Figure 19) and is termed "preferred discharge" for that species' spawning. Obviously, the preferred discharge cannot always be maintained as a minimum discharge; thus, the recommended minimum spawning discharge is defined as not less than 75 percent of the preferred spawning discharge.

Recommendations for rearing discharges are made by using a plot such as that shown on Figure 20A. For a more detailed analysis, Collings (1972) proposes use of the following approach when species rearing habitat criteria becomes available. Families of curves of velocity versus discharge and depth versus discharge are drawn as shown in Figure 20. From these curves, the area of the reach having specific velocities or depths, as defined by certain species criteria, can be determined from a selected discharge. For example, at a discharge of 70 cfs, about 79 percent of the reach has velocities of less than 1.2 feet per second. When preferred rearing depths and velocities have been

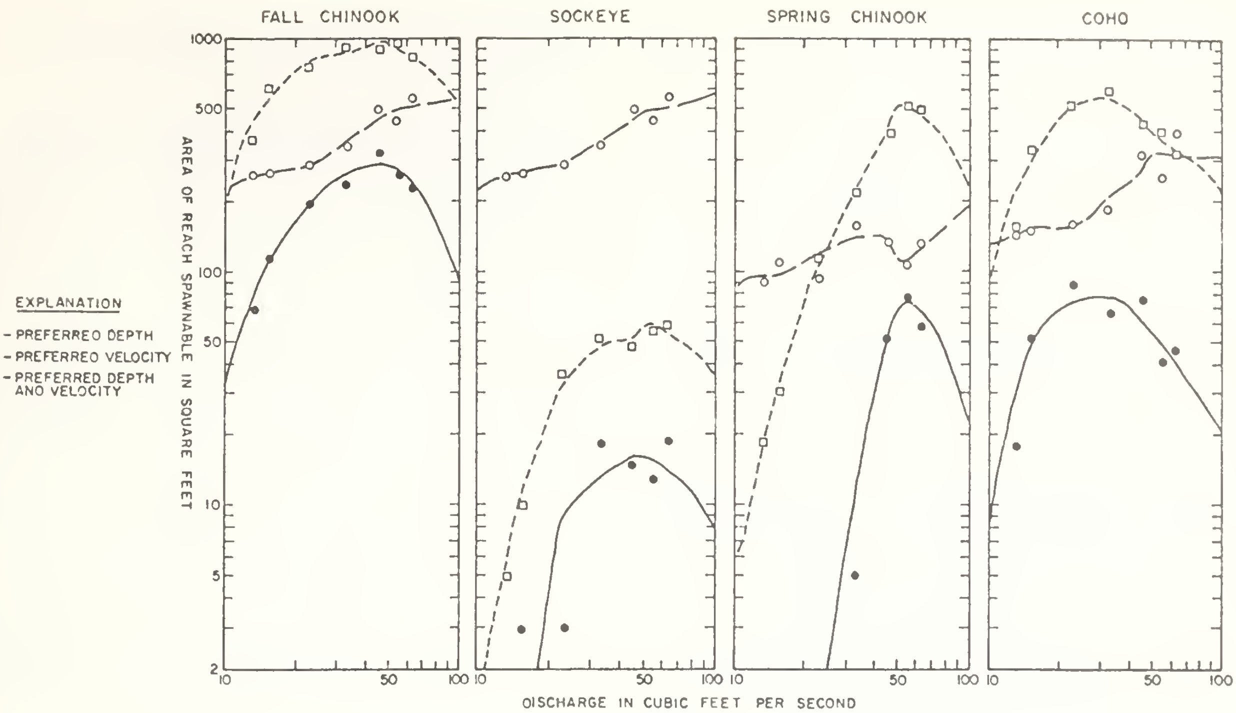



Figure 18. Curves of spawnable area versus discharge for North Nemah River (from Collings, 1972).

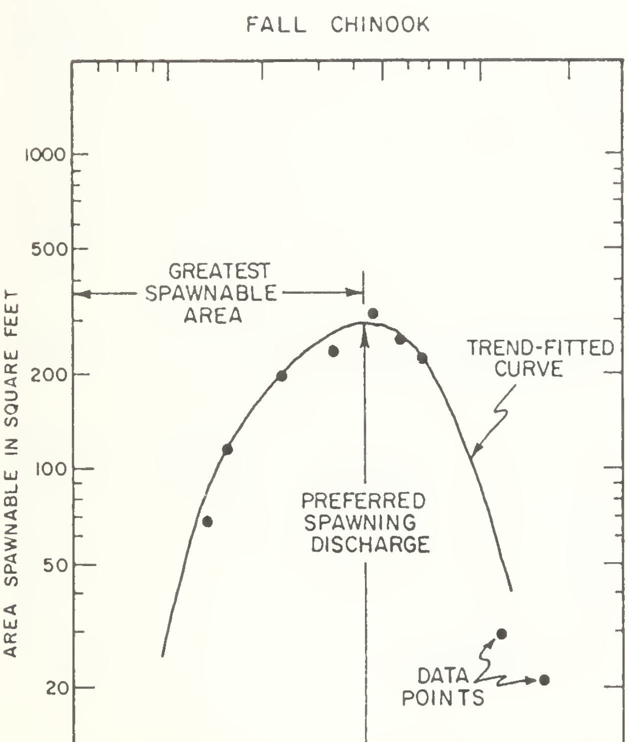
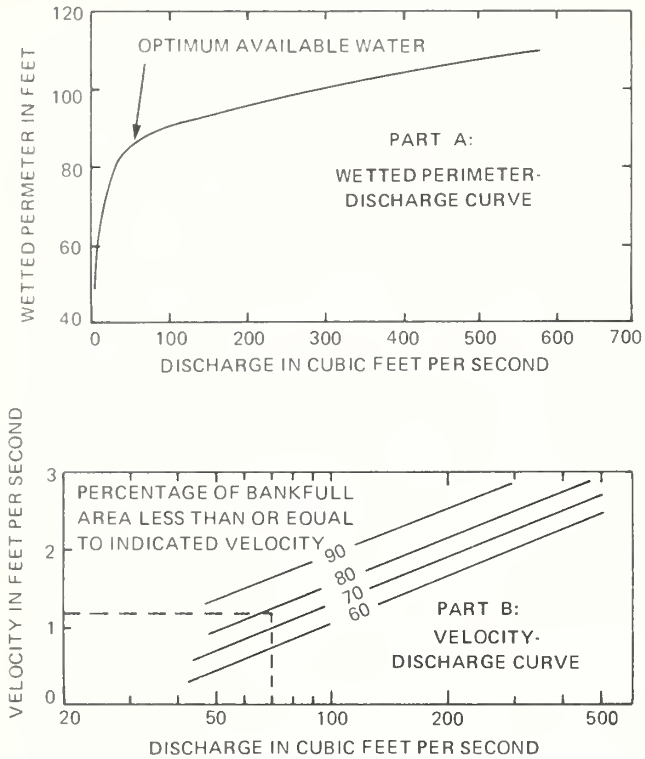



Figure 19. Method used to select the preferred spawning discharge, North Nemah River (from Collings, 1972).

determined, the curves in Figure 20, parts B and C, can be used to determine a rearing flow. For example, assuming critical velocities were between 1.0 and 1.2 feet per second, the discharge containing the greatest reach within the critical velocities may be selected as shown in part B of Figure 20. In essence, a discharge is selected and then the percentage of bankfull surface-water area at each of the velocities is picked.

Oregon Method (Usable Width)
(Thompson, 1972 and 1974)

The Oregon Method is based on criteria which reflect flow depth and velocity requirements in terms of one or more of the following




| ARBITRARILY SELECTED DISCHARGE (c.f.s.) | PERCENTAGE OF BANKFULL AREA FOR: 1.0 f.p.s. | PERCENTAGE OF BANKFULL AREA FOR: 1.2 f.p.s. | PERCENTAGE OF BANKFULL AREA HAVING VELOCITIES BETWEEN 1.0 AND 1.2 f.p.s. |
|---|---|---|---|
| 100 | 60 | 65 | 5 |
| 70 | 71 | 79 | 8 |
| 50 | 82 | 86 | 4 |

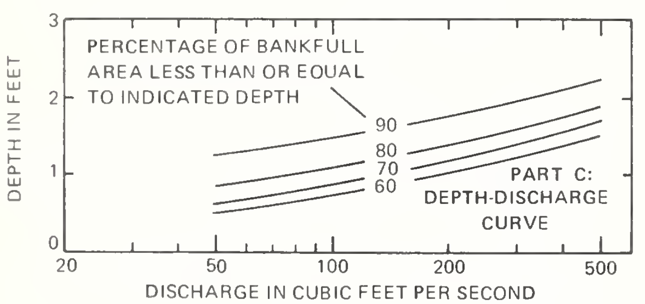



Figure 20. Example of curves used to determine and evaluate rearing discharges at each river study reach, as shown by curves for Elochoman River, Study Reach C (from Collings, 1972).

biological activities: passage, spawning, rearing, or incubation.

Equipment list includes the following: (1) waders, (2) transect stakes and hammer, (3) tape measure, (4) field data forms, (5) current meter, (6) depth rod, and (7) stop watch.

Methods for determination of those flow requirements are as follows:

1. Passage--Field Methods
   a. Locate shallow bars most critical to passage of adult fish and mark a linear transect which follows the shallowest course from bank to bank.
   b. At each of several flows, ranging from high flow to low flow, measure the total width and longest continuous portion of the transect which meets minimum depth and maximum velocity criteria (Tables 10 and 11 are examples).

Table 10. Salmonid passage criteria (from Thompson, 1972).

| Species | Minimum Depth | Maximum Velocity |
|---|---|---|
| Chinook | 0.8' | 8.0 fps |
| Coho, chum, steelhead, and large trout | 0.6' | 8.0 fps |
| Trout | 0.4' | 4.0 fps |

Table 11. Passage cross-section data (from Thompson, 1972).

| Flow | Date | Total Width | Width Wetted | Width Usable Feet | Width Usable % | Long. Cont. Port. | Usable % |
|---|---|---|---|---|---|---|---|
| 190 | 9-24-71 | 1000' | 460' | 22 | 2 | 11' | 1 |
| 1035 | 9-28-71 | 1000' | 820' | 754 | 75 | 722' | 72 |
| 1570 | 9-29-71 | 1000' | 1000' | 950 | 95 | 620' | 62 |
| 739 | 10-13-71 | 1000' | 940' | 627 | 62 | 627' | 63 |
| 479 | 10-14-71 | 1000' | 810' | 490 | 49 | 304' | 30 |

--Office Methods

a. Select the flow, for each transect, which meets the criteria on at least 25 percent of the total transect width and a continuous portion equaling at least 10 percent of its total width (Figure 21).

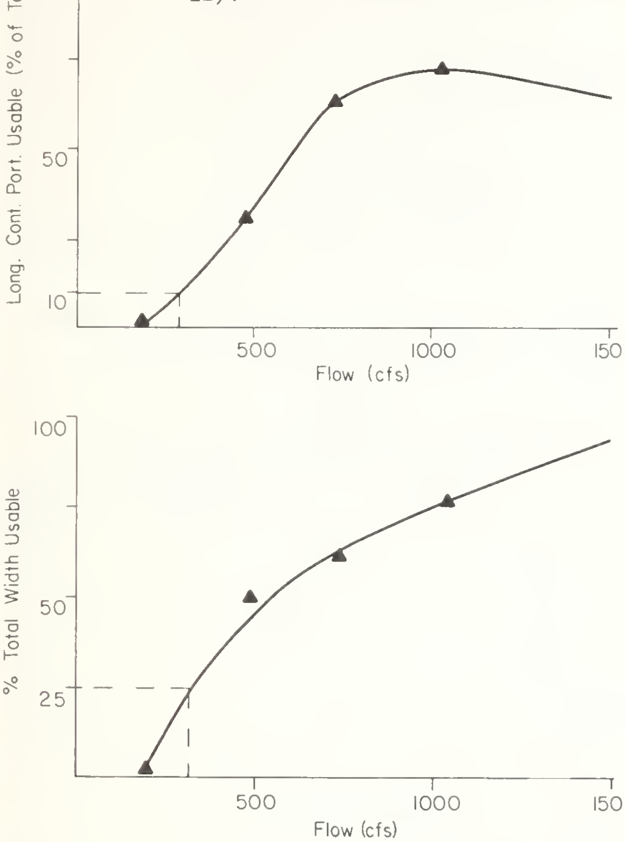



Figure 21. Example curves for determining flow requirements for passage (from Thompson, 1972).

b. The result averaged from all transects is the minimum flow recommended for passage.

2. Spawning--Field Methods

a. Select three gravel bars which represent the typical dimensions of those occurring in the stream reach.

b. On each gravel bar, mark a transect which coincides with the area where spawning is most likely to occur (based on biologist's experience).

c. At each of several flows ranging from high to low, the total portion of the transect is measured where flow conditions meet depth and velocity criteria (Table 12 and Figure 22).

Table 12. Salmonid spawning criteria (from Thompson, 1972).

| | ChF | ChS | Co | CS | St | Br | K | Other Trout |
|---|---|---|---|---|---|---|---|---|
| Water Velocity (fps) | 1.0 to 3.0 | 1.0 to 3.0 | 1.0 to 3.0 | 1.5 to 3.2 | 1.0 to 3.0 | 0.7 to 2.1 | 0.8 to 2.1 | 1.0 to 3.0 |
| Water Depth (ft) | 0.8 | 0.8 | 0.6 | 0.6 | 0.6 | 0.8 | 0.4 or 0.6 | 0.4 or 0.6 |
| Sample | 440 | 158 | 251 | 177 | 363 | 115 | 106 | |

--Office Methods

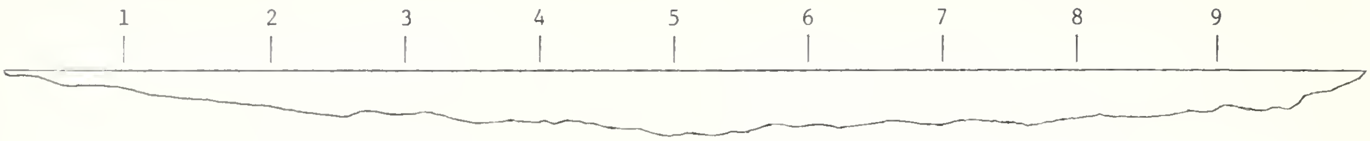
a. Assess the mean relationship between discharge and usable gravel area for spawning from all transects.

b. An optimum spawning flow is that which provides suitable flow depth and velocity conditions over the most gravel. The discharge which created suitable flow conditions over 80 percent of the gravel available at an optimum spawning flow has been recommended for minimum spawning (Table 13 and Figure 23).

3. Incubation--Field Methods

a. At each of several flows, estimate the flow required to cover gravel areas used for spawning and to create an intra-gravel environment conducive to successful egg incubation and fry emergence. This generally amounts to about 2/3 the flow required for spawning.

b. To strengthen the recommendation Thompson (1974) incorporated into the methodology the measurement over a range of flow levels (3 to 5) of intra-gravel dissolved oxygen content and the survival success of eyed salmonid eggs planted in suitable spawning gravels. The primary incubation flow criterion was the maintenance of at least 5.0 ppm intra-gravel dissolved oxygen content in the available gravel at spawning flows.




SPAWNING BAR CROSS SECTION

| Station | Depth (ft) | Velocity (frs) |
|---|---|---|
| 1 | 0.4 | 1.4 |
| 2 | 0.6 | 1.6 |
| 3 | 0.7 | 1.9 |
| 4 | 0.9 | 2.3 |
| 5 | 1.1 | 3.1 |
| 6 | 1.0 | 2.6 |
| 7 | 0.8 | 2.0 |
| 8 | 0.7 | 1.4 |
| 9 | 0.6 | 0.9 |

Spawning Flow Criteria

Minimum depth - 0.6'

Velocity - less than 3.0 but greater then 1.0 f.p.s.

Flow = Width x m Depth x m Velocity

Flow = 25' x 0.75 x 1.93 fps

= 36 CFS

Stream Width Usable for Spawning

$$\text{Usable width} = \frac{\text{stream width}}{10} \times \#\ \text{usable stations}$$

$$= \frac{25'}{10} \times 6$$

$$= 15.0'$$

Figure 22. Spawning bar cross section (from Thompson, 1972).

Table 13. Determining spawning flows (from Thompson, 1972).

| Flow (cfs) | Usable Width (ft) |
|---|---|
| 7 | 2 |
| 10 | 6 |
| 15 | 9 |
| 22 | 12 |
| 36 | 15 |
| 45 | 22.5 |
| 61 | 18 |

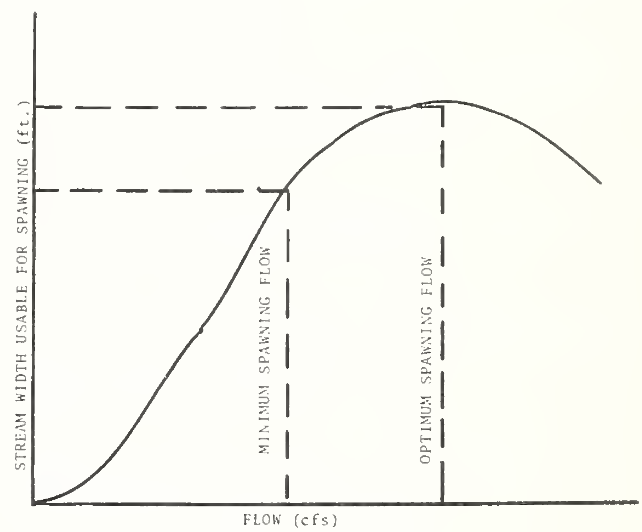



Figure 23. Determining spawning flows (from Thompson, 1972).

This, coupled with the knowledge of the spawning gravels covered by the recommended spawning flow, serves as the basis for the incubation flow recommendation.

Intra-gravel dissolved oxygen should be sampled at each study flow level by means of plastic standpipes driven down twelve inches into spawning gravels. The standpipes are deployed along the same gravel transects used to evaluate spawning flow requirements. Intra-gravel dissolved oxygen is measured by means of the following technique, as provided by Thompson (1974):

"1) Try to establish standpipes in area so dissolved oxygen readings can be taken as late in the day as possible (to allow as much time as possible for intra-gravel environment to stabilize after each flow transition).

2) Drive standpipes into gravel just upstream from spawning transect. Add additional standpipes on each transect as soon as reduced flow stages permit. Metal reinforcing rods can serve to stabilize the standpipes in swift river currents.

3) Blow on top of standpipe to clear it of sediments. (Watch for bubbles around base of standpipe. Relocate standpipe in vicinity if it cannot be cleared.)

4) Allow at least 6 hours for substrate and DO around base of pipe to stabilize. (Wait as long as possible after a flow stage has stabilized before sampling DO. Preferably, sampling should be done just prior to the subsequent flow stage or just prior to darkness. Each daily sampling should be done at the same time of day.)

5) With hand thermometer and string, take temperature of water in bottom of standpipe prior to testing DO.

6) Before extracting water sample, clear rubber sampling tubes of all excess water (this can be accomplished by grasping the cork end and twirling the rubber sampling tubes).

7) To obtain water sample from standpipe, insert longest rubber tube well into water column but do not allow it to touch bottom where it could pick up sediments. Place short rubber tube in mouth and carefully draw water sample, pinching tube with teeth or fingers between breaths to avoid letting water recede in sampling tube and air to become trapped in tube or sample bottle. Discard sample and repeat procedure if bubbles should appear.

8) When filling sample bottle, tilt bottle slightly to side to allow sample water to run down inside of bottle, thus avoiding aeration.

9) As soon as sample bottle is filled, gently remove stopper and raise ends of rubber tubing above bottle to allow excess water to overflow.

10) Pour a small amount of water from sampling bottle to allow enough space for adding reagents.

11) Add $MnSO_4$ to water sample. Tap neck of sampling bottle with glass stopper to settle reagents from surface.

12) Add alkaline iodide-sodium azide. Replace glass stopper in water sample bottle with a quick twist. Tilt bottle slightly.

13) Shake sample bottle 5-10 seconds to dissolve chemicals.

14) Set bottle down to allow floc to settle halfway (if floc does not settle, allow 2 minutes to insure the process to reliably continue).

15) Add $H_2SO_4$ (after adding $H_2SO_4$, water sample is considered "fixed" and can be allowed to stand as long as desirable before titrating).

16) So that each drop PAO equals 1/2 part per million, place two cylinders full of water sample into titration container.

17) Add two drops of starch indicator to titration container with sample and mix.

18) Withdraw eye dropper filled with PAO and discard first drop.

19) Commence titrating with PAO, adding one drop at a time to water sample in titration container. Be sure to swirl water sample after each drop of PAO is added, especially near end point. End point is reached when water color returns to that of the water sample before any reagents were added.

20) Rinse all glassware in river water.

21) A subsequent water sample may be drawn from standpipe within 10-15 minutes.

22) Monitor each standpipe daily (at same time of day) as long as water sample can be drawn from standpipe. When water sample can no longer be drawn from standpipe, note the day, and pull the standpipe for use elsewhere to supplement subsequent measurements.

23) Reinforcing rods can be removed from standpipe after surface depth drops below 1.0'. This will enable the use of the bracing for standpipes subsequently established."

For a further description of the use of standpipes to evaluate spawning gravels, the reader is directed to Terhune (1958) and Reiser and Wesche (1977).

4. Rearing--Field Methods

   a. At each of several flows an estimate is made of the flow required to create a suitable stream environment for rearing based on the following guidelines:

      1) Adequate depth over riffles.

      2) Riffle-pool ratio near 50:50.

      3) Approximately 60 percent of riffle area covered by flow

      4) Riffle velocities 1.0 to 1.5 fps.

      5) Pool velocities 0.3 to 0.8 fps.

      6) Most stream cover available as shelter for fish.

   --Office Methods

   a. The flow which the various estimates indicate is recommended for rearing.

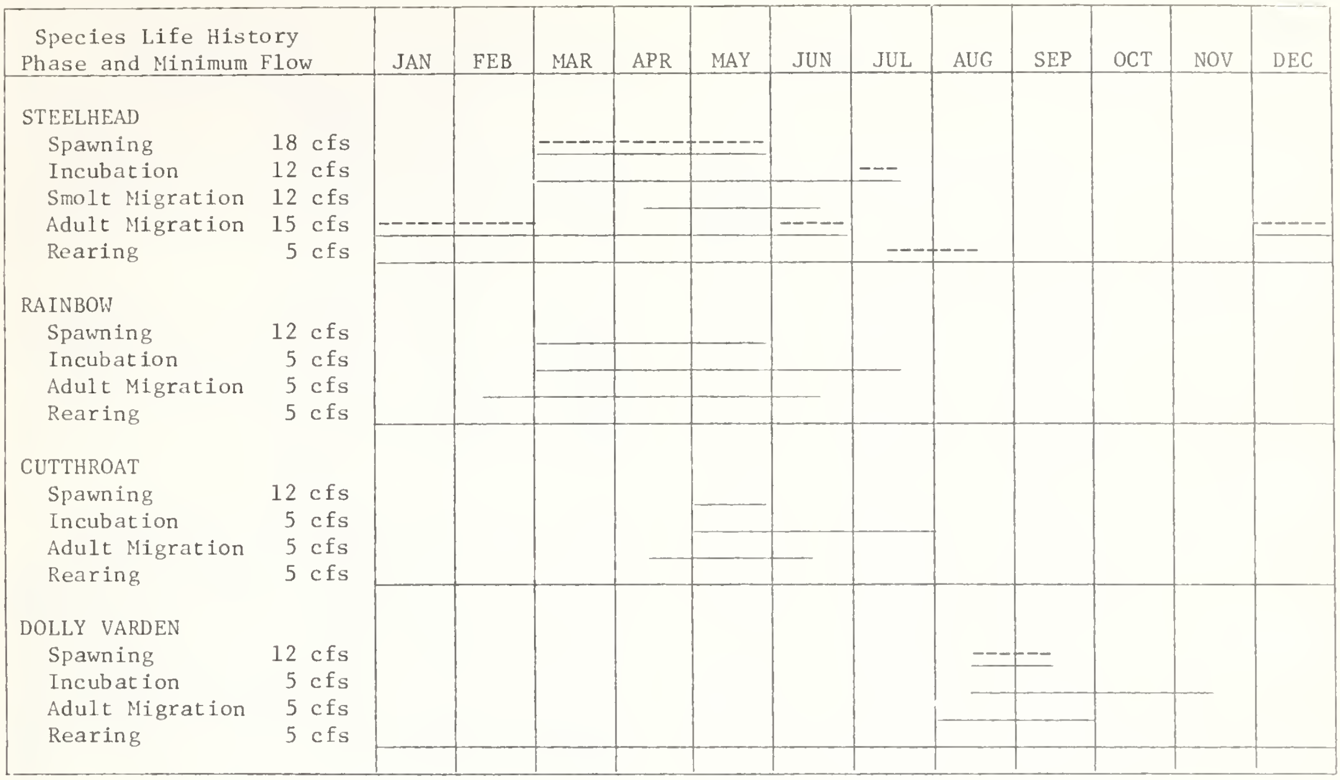
With a flow recommendation for each of the four biological activities for each important species in the reach, a chart depicting the life history periodicities (Figure 24) is prepared. The flows required for passage, spawning, incubation, and rearing for each species are assigned to their respective periods illustrated on the chart. The flow selected for any month of two-week period is the highest flow required to accommodate any biological activity during that period. The highest flows required by month for 12 consecutive months is the regimen usually selected as required.

## Weighted Usable Width Method
(Sams and Pearson, 1963)

The weighted usable width method is an offshoot of the Oregon Usable Width Method, which, through the use of weighting factors for various hydraulic categories of spawning habitat, adds additional biological emphasis to the recommendation. Field methods and equipment needs are the same as the Oregon Method. The following discussion summarized from Sams and Pearson (1963) presents the variations in office technique.

The weighted usable width analysis is a refinement of the usable width method. The premise of this method is that stream widths with velocities in which 2 percent of the redd measurements fall would not have an equal value as those velocities in which 30 percent of the redd measurements fall. The high and low velocities are weighted using a factor calculated from the velocity distribution of the redd measurements for each species of salmonid.

The procedure for the weighted usable width method is the same as the usable width method except in obtaining the usable width from the velocity distribution curve for a particular cross section. In the weighted usable analysis, each velocity category from the weighted velocity table (Table 14) is marked off on the velocity distribution curve for each cross section. Then the width which falls into a particular velocity category is




| Recommended Minimum Flow Regimen | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15 | 15 | 18 | 18 | 18 | 15 | 12/5 | 5/12 | 12/5 | 5 | 5 | 15 |

Figure 24. Life history periodicity and minimum flow regimen for existing salmonid populations in Reynolds Creek, John Day Basin (from Thompson, 1972).

multiplied by the appropriate factor from the weighted velocity table. The answers thus obtained are added to find the weighted usable width. For example, a segment of a coho salmon spawning cross section is 5 feet wide, with velocities between 1.65 and 1.95 feet per second; and other segment is 10 feet wide, with velocities between 1.25 and 1.65 feet per second. From the table of weighted velocities it is seen that the 5 feet is multiplied by the factor of 0.8 and the 10 feet is multiplied by 1.0. The total of these values gives a weighted usable width of 14 feet. After the percent usable width is calculated for each flow, a curve is drawn to make a flow determination as in the usable width analysis.

### WRRI Trout Cover Rating Method (Wesche, 1973 and 1974)

Wesche (1973, 1974) has developed a detailed method of cover measurement, based upon species and size class preferences for major types of cover. From the analysis of the cover used by 1,160 trout (primarily browns) in Wyoming's smaller streams (average discharges less than 100 cfs), the following cover rating equation has been developed:

$$CR = \frac{L_{obc}}{T} (PF_{obc}) + \frac{Ar - b}{SA} (PFr - b)$$

where

$L_{obc}$ = length of overhead bank cover in the study section having a water depth of at least 0.50 feet and a width of 0.3 feet or greater;

$T$ = length of the thalweg line through the section;

$PF_{obc}$ = preference factor for overhead bank cover;

Table 14. Spawning velocity categories and weighting factors for weighted usable width analysis (Sams and Pearson, 1963).

| Species | Velocity Category (cm/sec) | (ft/sec) | Weight Factor |
|---|---|---|---|
| Spring Chinook Salmon (*O. tschawytcha*) | 7.6-19.8 | 0.25-0.65 | 0.1 |
| | 19.8-22.9 | 0.65-0.75 | 0.4 |
| | 22.9-25.9 | 0.75-0.85 | 0.8 |
| | 25.9-56.4 | 0.85-1.85 | 1.0 |
| | 56.4-59.4 | 1.85-1.95 | 0.9 |
| | 59.4-62.5 | 1.95-2.05 | 0.6 |
| | 62.5-68.6 | 2.05-2.25 | 0.5 |
| | 68.6-77.7 | 2.25-2.55 | 0.2 |
| | 77.7-86.9 | 2.55-2.85 | 0.1 |
| Fall Chinook Salmon (*O. tschawytcha*) | 27.4-33.5 | 0.90-1.10 | 0.2 |
| | 33.5-42.7 | 1.10-1.40 | 0.6 |
| | 42.7-67.1 | 1.40-2.20 | 1.0 |
| | 67.1-76.2 | 2.20-2.50 | 0.4 |
| | 76.2-88.4 | 2.50-2.90 | 0.2 |
| | 88.4-94.5 | 2.90-3.10 | 0.1 |
| Coho Salmon (*O. kisutch*) | 13.7-16.8 | 0.45-0.55 | 0.1 |
| | 16.8-25.9 | 0.55-0.85 | 0.2 |
| | 25.9-32.0 | 0.85-1.05 | 0.6 |
| | 32.0-38.1 | 1.05-1.25 | 0.8 |
| | 38.1-50.3 | 1.25-1.65 | 1.0 |
| | 50.3-59.4 | 1.65-1.95 | 0.8 |
| | 59.4-68.6 | 1.95-2.25 | 0.4 |
| | 68.6-74.7 | 2.25-2.45 | 0.2 |
| | 74.7-93.0 | 2.45-3.05 | 0.1 |
| Steelhead Trout (*S. gairdneri*) | 36.6-45.7 | 1.20-1.50 | 0.4 |
| | 45.7-73.2 | 1.50-2.40 | 1.0 |
| | 73.2-85.3 | 2.40-2.80 | 0.6 |
| | 85.3-103.6 | 2.80-3.40 | 0.2 |

Ar-b = surface area of the study section having water depths greater than 0.50 feet and substrate size 3.0 inches in diameter or greater (i.e., rubble and boulder);

SA = total surface area of the study section at the average discharge, or at the flow worked (explained later on page 53);

PFr-b = preference factor for instream rubble-boulder areas;

CR = cover rating value for the study section at the discharge worked.

Field methods are described below. The equipment needed in the field to make a trout cover rating includes the following: (1) 50 or 100 foot cloth or steel tape, (2) depth rod, (3) waders, (4) wood or metal survey stakes, (5) hammer, and (6) field book.

Following is a detailed description of the field procedures to be used.

1. Select a study site. This can be done by either a random, a systematic, or an individual judgment selection procedure, dependent upon the objectives of the investigator. Ratings can be made on any length of stream section.

2. Walk the site. Do this to become familiar with the physical characteristics of the habitat. Note such factors as substrate, water surface turbulence, top width, water depths, riffle-pool sequences, brush and log jams, streambank vegetation, and location of the thalweg.

3. Select cross-channel transects. Based upon your observations made under #2 above, select cross-channel transects which represent the variety of habitat types present. Each individual transect should be chosen as representative of a given area of the study site (see Figure 25). There is no set rule-of-thumb as far as the number of transects needed. On this point, let the habitat be your guide. Mark each transect on each streambank with metal or wooden stakes.

4. Measure across the transects. Stretch a tape or tag line between the two stakes at each transect. Beginning at the left bank stake, measure the distance to the water's edge. From the edge, proceed across the channel, measuring water depth (to the nearest 0.05 feet) and classifying the substrate types present at selected intervals (Figure 25). The following substrate classes should be used:

| Type | Diameter (inches) |
|---|---|
| Silt | <0.04 |
| Sand and fine gravel | 0.04-1.25 |
| Coarse gravel | 1.26-3.0 |
| Rubble | 3.0-12.0 |
| Boulder | >12.0 |

The purpose of classifying the substrate is to define those areas composed of rubble and/or boulders (diameter greater than 3 inches). Each measurement across the transect should represent no more than 10 percent of the wetted stream width (i.e., if the stream is 30 feet wide, the maximum distance between measurements would be 3 feet). This is a modification of the standard procedure for measuring discharge, in which no measurement should include more than 10 percent of the total flow (Linsley, Kohler and Paulhus, 1975).

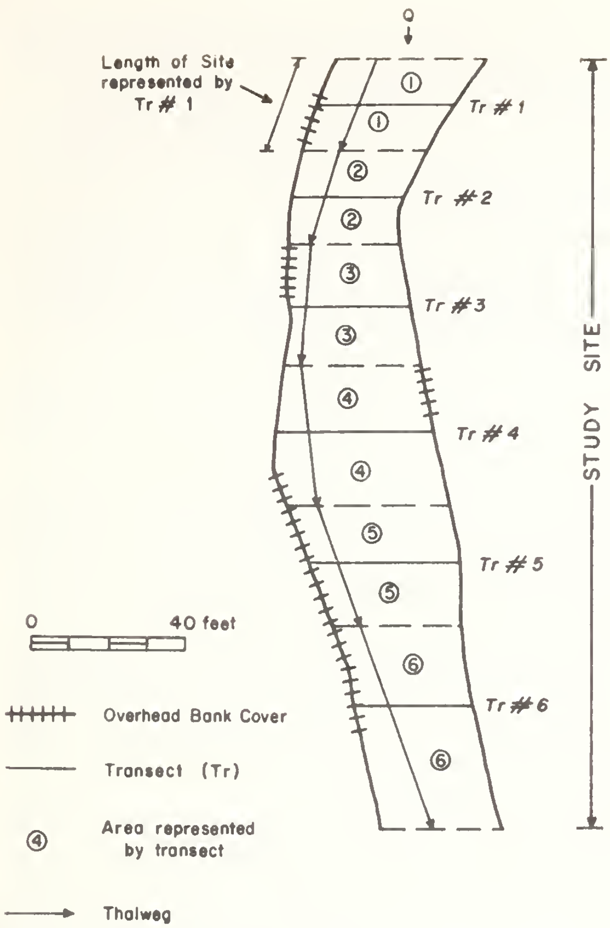



Figure 25. Example study site for making a trout cover rating. Note: A map such as this need not be prepared to make a covering rating.

Each transect should be given a number and the depth and substrate present at each measurement location should be recorded on high-grade paper having a water-resisting surface sizing, such as that found in a K & E transit book. Table 15 presents an example of raw transect data.

5. Measure the surface area. For each transect selected and measured, you have already determined the stream width at that location. To obtain the wetted surface area represented by a given transect, multiply the width by the length of the stream section represented. Summing the surface area values for each transect gives the total surface area for your study site. Summing the individual lengths gives you the total length.

Table 15. Example of transect data.

TRANSECT #1

| Distance (ft) | Width (ft) | Depth (ft) | Substrate | Cover Width (ft) |
|---|---|---|---|---|
| 0 | -- | dry | -- | -- |
| 3-edge | 1.5 | 0.10 | St | 0 |
| 6 | 3.0 | 0.30 | St | 0 |
| 9 | 3.0 | 0.40 | Sd-FG | 0 |
| 12 | 3.0 | 0.50 | Sd-FG-CG | 0 |
| 15 | 3.0 | 0.65 | CG-R | 1.5 |
| 18 | 3.0 | 0.75 | R | 3.0 |
| 21 | 3.0 | 0.90 | R | 3.0 |
| 24 | 3.0 | 1.05 | R-B | 3.0 |
| 27 | 3.0 | 1.20 | R-B | 3.0 |
| 30 | 3.0 | 0.95 | R-B | 3.0 |
| 33 | 3.0 | 0.80 | R | 3.0 |
| 36 | 3.0 | 0.75 | CG-R | 1.5 |
| 39 | 1.5 | 0.75 | CG | 0 |
| | 36.0 | | | 21.0 |

Notes:

Length of study site represented = 26 ft.

St - Silt; Sd - Sand; FG - Fine gravel; CG - Coarse gravel; R - Rubble; B - Boulder.

6. Measure the overhead bank cover. This cover category includes undercut banks, logs, brush jams, and overhanging vegetation (such as willows). The measurements needed include the lengths of these types present, their widths, and the associated water depths. To do this, stretch a tape along the length of the overhead cover section to be measured. Contour your tape to the bank itself, as in many situations the section will be curved (as at a bend) and have many "nooks and crannies." Depth and width measurements are then taken along the tape at selected intervals (Figure 26). As with the transects, each measurement point should represent no more than 10 percent of the length (i.e., if the overhead cover section is 20 feet long, the maximum distance between measurements would be 2 feet). While this "rule-of-thumb" works well for longer sections (greater than 10 feet), it often results in excessive measurements for sections less than 10 feet. To avoid this problem, take measurements at one-foot intervals in sections less than 10 feet. The purpose of depth and width measurements is to determine the number of linear feet of overhead cover which are at least 0.3 feet wide and are associated with depths of at least 0.50 feet.

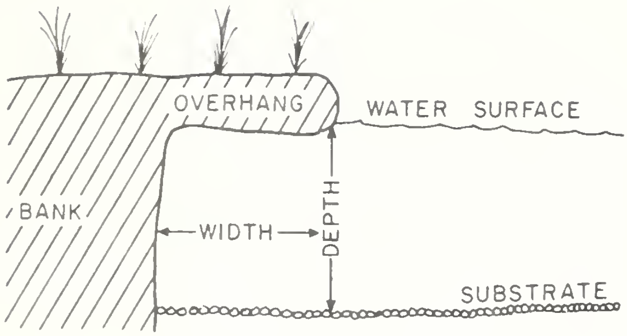



Figure 26. Location of depth and width measurements for overhead bank cover.

This completes the field work necessary for making a cover rating. The data you have gathered should include:

a. depths and substrate types along your transects;

b. widths of transects and the length of stream which each transect represents;

c. total length of study site; and

d. length of all overhead bank cover types with associated water depths and overhang widths.

It is recommended that a discharge measurement be taken at the same time as the cover rating, as the primary use of such ratings is to compare available cover at one flow with that at another flow level. If this is your objective (comparison of different flow levels), leave your transect stakes in place for future use.

Office methods are discussed below.

The "Cover Rating Form" (Figure 27) on the following page presents all the data inputs and calculations necessary to complete a cover rating. Comments concerning this form are as follows:

1. Stream. Enter name of river or creek investigated.

2. Location. Enter township, range, and section, plus any other pertinent descriptions.

3. Flow. Enter discharge, in cfs, at the time of the field measurement.

4. Average Discharge. Obtain from USGS Surface Water Records for the stream reach studied (if available).

5. Date. Enter year, month, day, and time (a.m. or p.m.) at which field measurements were taken.

6. Salmonid Species. List the names of the species known to be present in order of decreasing abundance (this information can be from personal observations, agency records, or on-site electrofishing).

7. Non-Salmonid Species. List the names of non-salmonid species known to be present.

8. Standing Crop. Record here if estimates for trout population were made at the time of field cover measurements. Note: This information is not necessary for making a cover rating.

9. Comments. Enter other features of the study section of interest to the investigator.

10. Field Data Collected By. Enter name of field investigator.

11. Office Calculations By. Enter name of person calculating the cover rating.

12. Transect #. Enter the number of each transect for the study site; begin with #1 and proceed down the column.

13. Wetted Top Width. Enter the wetted width for each transect as determined by your field transect data (see example in Table 15).

14. R-B Cover Width. For each transect, enter the number of feet of wetted top width which had a water depth of at least 0.50 feet and a rubble (R) and/or boulder (B) substrate (see example in Table 15); if the water depth is adequate but the substrate is a mix of rubble and a smaller type, such as coarse gravel, the cover width value is one-half of the width value.

15. Length of Section. For each transect, enter the length of the stream section, as measured along the thalweg line, which the transect represents. The total of these values will be the total length of your study site.

16. Surface Area Represented. For each transect, enter the product of the wetted top width and the length of section. The total of these values will be the total surface area of your study site.

WRRI TROUT COVER RATING FORM

Stream Example Creek Location T13N, R79W, Sec. 19; near Hypothetical, Wyoming

Flow (cfs) 10 Average Discharge (cfs) 25 Date 8/17/75 p.m.

Salmonid Species Brown trout, brook trout

Non-Salmonid Species Longnose suckers, white suckers, longnose dace

Standing Crop -- lbs./acre -- #/acre

Comments Site relatively straight; little surface turbulence and no aquatic vegetation.

Field Data Collected by T. A. Wesche and C. O. Cooper

Office Calculations by T. A. Wesche

| Transect # | Wetted Top Width (ft) | R-B Cover Width (ft) | Length of Section (ft) | Surface Area Represented (sq ft) (TW x L) | R-B Cover Area (sq ft) (Cover W/TW) x SA |
|---|---|---|---|---|---|
| 1 | 36 | 21 | 26 | 36 x 26 = 936 | (21/36) 936 = 546 |
| 2 | 29 | 14 | 25 | 29 x 25 = 725 | (14/29) 725 = 350 |
| 3 | 32 | 22 | 33 | 32 x 33 = 1056 | (22/32) 1056 = 726 |
| 4 | 41 | 8 | 37 | 41 x 37 = 1517 | (8/41) 1517 = 296 |
| 5 | 40 | 12 | 31 | 40 x 31 = 1240 | (12/40) 1240 = 372 |
| 6 | 31 | 15 | 54 | 31 x 54 = 1674 | (15/31) 1674 = 810 |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| TOTALS | | | 206 | 7148 | 3100 |

$$CR = \frac{L_{obc}}{L_t}(PF_{obc}) + \frac{Ar\text{-}b}{SA}(PFr\text{-}b)$$

CR = cover rating
$PF_{obc}$ = 0.75 ($\geq$6.0") and 0.50 (<6.0")
$PF_{r-b}$ = 0.25 ($\geq$6.0") and 0.50 (<6.0")
$L_{obc}$ = length available overhead bank cover (ft) = 102
$L_t$ = length thalweg (ft) = 206
Ar-b = rubble-boulder area (sq ft) = 3100
SA = total surface area (sq ft) = 7148

$$CR(<6.0") = \frac{102}{206}(.50) + \frac{3100}{7148}(.50) = 0.464$$

$$CR(\geq 6.0") = \frac{102}{206}(.75) + \frac{3100}{7148}(.25) = 0.480$$

$$CR(mean) = \frac{0.464 + 0.480}{2} = 0.472$$

Figure 27. Example of trout cover rating form.

17. R-B Cover Area. For each transect, divide the rubble-boulder cover width by the wetted top width (this gives the percentage of the transect which meets the cover criteria) and multiply this quotient by the surface area which the transect represents. The total of these values will be the total rubble-boulder cover area of your study site.

18. Calculation of Cover Rating Values. All of the data necessary for calculating the cover rating values for your study site at the discharge present on the day of field measurement are now generated. Simply plug in your numbers and select the proper preference factor values for your purposes (i.e., if you're interested in available cover for juvenile, sub-catchable trout, use $PF_{obc}$ of 0.50 and PFr-b of 0.50; for a cover rating for catchable trout, use $PF_{obc}$ of 0.75 and PFr-b of 0.25; if you're interested in all size classes together, average your subcatchable and catchable ratings to obtain a mean cover rating and calculate your cover rating values).

19. Use of Cover Ratings for IFN Determinations. The primary use of cover ratings is to quantify the amount of trout cover available for a given study site at various flow levels so that a flow-cover plot can be developed, such as that shown on Figure 28. If this is your objective, the following guideline applies in regard to the total surface area value (SA) used:

> "The surface area value used for calculations at all flow levels for a given study site should be that value measured at the highest flow level for which a cover rating is being made" (Wesche, 1974).

The following example points out the reason for this:

$\frac{Ar\text{-}b}{SA}(PF_{r\text{-}b})$ = the rubble-boulder portion of the cover rating

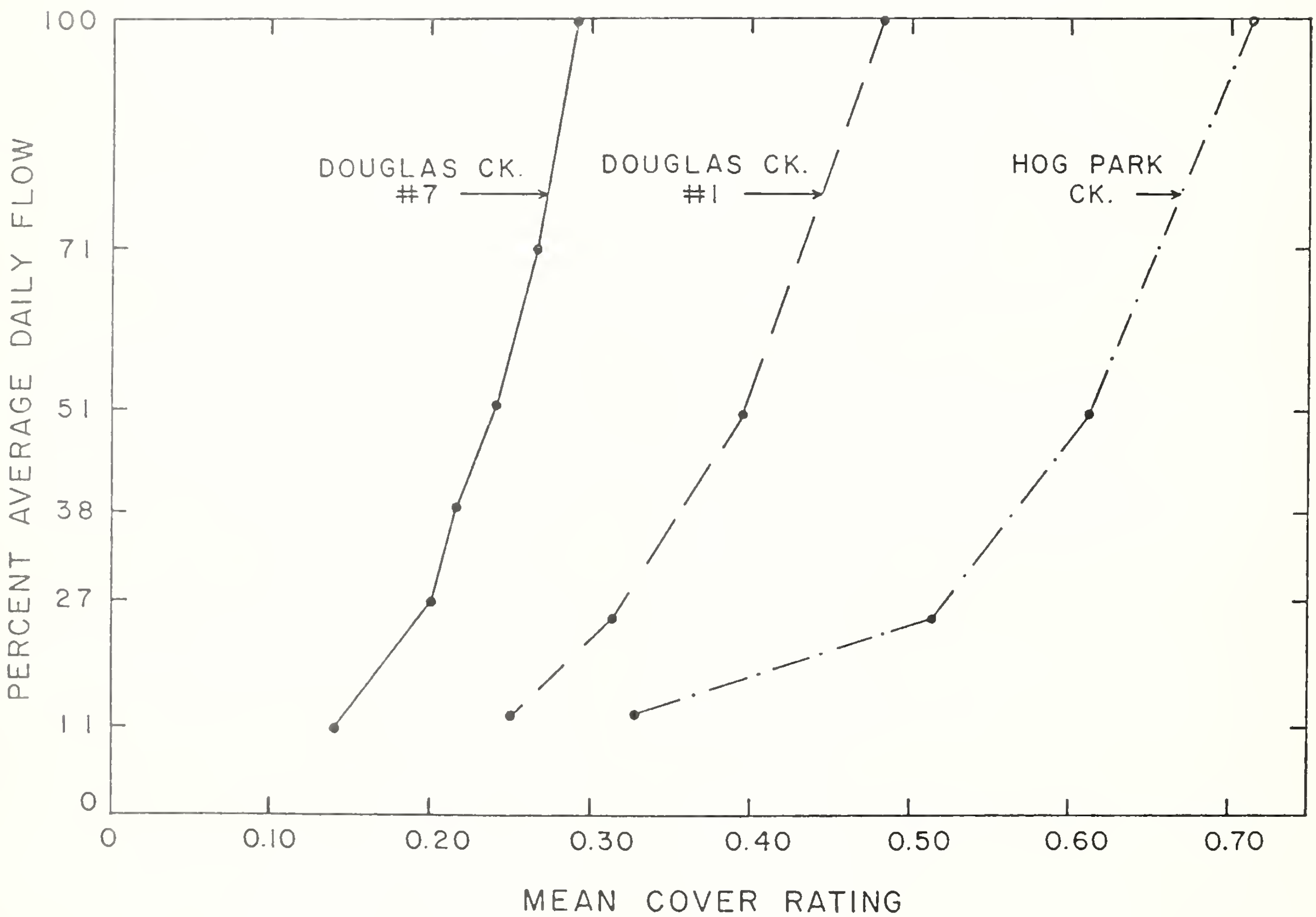



Figure 28. Loss of available trout cover as flow was reduced at three study sites.

For our Example Creek study site at 10 cfs, (3100/7148) (.50) = 0.217. For this site at 5 cfs, (2800/5000) (.50) = 0.280. As this example shows, since we are dealing with ratios, it would be possible to come up with a higher rating for rubble-boulder cover at a lower flow because total surface area (SA) decreased at a much greater rate than did the rubble-boulder cover area (Ar-b). Thus, at 5 cfs, the total surface area value for 10 cfs should be used to accurately assess the cover loss: (2800/7148) (.50) = 0.196.

Wesche (1974), analyzing the plot shown on Figure 28, found that available trout cover is reduced at its greatest rate as flow drops below the 25-27 percent of average discharge (A.D.) level. Using this as one criteria, he recommended that for summer trout rearing, flow should not be reduced below the 25 percent A.D. level.

As the cover rating system is based upon transect data and depth measurements along streambank cover located near those transects, it should be easily adaptable to a computer program such as R-2 Cross. This would allow the synthesis of cover ratings for water stage levels other than those measured in the field. Field procedures would remain the same as those described above, with the exception that the Forest Service sag-tape or tight-tape transect method should be used. Changes in total surface area could be estimated from the changes in wetted top widths at the transects, while changes in the rubble-boulder cover area could be determined from the variation in water stage. The length of the study site would, of course, remain constant from one flow to another, as would the preference factors. The only remaining parameter, the length of overhead bank cover in association with at least 0.50 feet of water, could be estimated by applying the change in water stage observed at the nearest transect.

It should be noted that cover has been measured by other investigators (Boussu, 1954; Lewis, 1967; Kraft, 1968; Hunt, 1969). Generally, these studies were conducted to show the effects of the addition or removal of cover on the standing crops of trout in given stream sections. While their objectives were not to develop methodologies for assessing the changes observed in cover due to flow fluctuation, the results are significant because they do help to illustrate the value of cover to trout populations. All measured existing cover is in square feet of overhanging bank or vegetation, submerged vegetation, submerged objects, or floating debris.

Data collection procedures required the following equipment: (1) tape and/or surveying rod and (2) waders.

These procedures were as follows: Measure with a tape or surveying rod the length of the particular unit of cover. Divide this length into equal sections and measure the width of the unit at each interval. Multiplying each width by each length gives square feet of cover for the interval. Total cover is obtained by adding the intervals together.

### Indicator-Species Overriding Consideration Method (Bovee, 1975)

This method is based on the premise that, "if environmental conditions are not unfavorable for the species with the narrowest ranges of discharge requirements, they will likely be suitable for all other organisms as well. An indicator species is defined as the species which demonstrates the narrowest range of tolerances or requirements for any particular biological function." The method recognizes three biological phases in fish life history: migration, spawning, and rearing.

Equipment list includes the following: (1) tape measure, (2) depth rod, (3) transect stakes and hammer, (4) current meter, (5) waders, (6) field data forms and (7) stop watch.

Field methods for data gathering are discussed below.

To recommend migration and spawning discharges, Bovee suggests the use of Oregon's usable width methodology. Step-by-step procedure is exactly the same as outlined in the Oregon Method. However, Bovee suggests the use of paddlefish or sauger for indicator species.

"At each of several discharges the total width and the longest usable portion of the transect meeting minimum depth and maximum velocity criteria are measured. The total usable width and the longest continuous portion of each transect are each plotted against discharge. Because the paddlefish requires a rise in stage of at least a meter, it is recommended that the discharge which meets clearance criteria over 50 percent of the total transect width and a continuous portion equalling at least 30 percent of the total transect width be used as the minimum migration requirement. These percentages may be subject to revision pending research on migration stimuli and passage requirements."

"For lower reaches of larger rivers, where the paddlefish normally spawns, the migration flow recommendation for the paddlefish may also be recommended as the spawning flow. Since paddlefish spawning is determined primarily by migration success, it is reasoned that adequate migrational discharges will also be adequate for spawning. Thus, for these rivers, the migration and spawning flow may be determined by the migration requirements of the paddlefish and extended over the three month period suggested."

"For reaches of streams which do not have spawning paddlefish, the indicator for spawning is the sauger. The criteria suggested for sauger spawning are those areas which provide the greatest egg survival. These areas generally lie over clean swept gravel bottoms where the depth ranges between 1.0 and 1.5 meters and the velocity ranges between 0.3 and 0.75 m/sec."

"The methodology suggested for the analysis of sauger spawning site suitability is exactly the same as the Washington Method. Six likely spawning sites are located which are representative of most of the spawning sites in the river. Four transects are established across each site, with cross sections about 10 meters apart. The depth and velocity are measured at 0.5 meter intervals across each transect. Velocity should be measured at 0.6 of the total depth in water less than 0.5 meters deep and averaged from measurements taken at 0.2 and 0.8 of total depth in water deeper than 0.5 meters. Cross-sectional depth and velocity data for at least five different discharges are then plotted on separate planimetric maps of each study reach. Isolines of equal depth and velocity are drawn on the maps, and a composite map showing areas meeting criteria for depth and velocity is constructed for each discharge. These areas are then determined by planimeter or planimetric graph paper and plotted against discharge. The minimum sustaining discharge is defined at 75 percent of the optimum. This recommended spawning discharge should also be extended for at least three months, beginning with initiation of sauger spawning, to ensure the successful spawning of later spawning species (e.g., northern pike and smallmouth bass)." Table 16 presents spawning criteria for selected species of fish of the Northern Great Plains Region.

"Successful rearing of stream fishes requires that the food base is adequate, that food is consistently replenished through drift into the pool areas, and that microhabitat and water quality requirements of the species inhabiting the pool areas are met. Because riffle areas are more seriously affected by reduced discharges, it is reasoned that the maintenance of suitable riffle conditions will result in suitable pool conditions as well. For this reason, a swift water species, the stonecat (Notorus flavus), is chosen as the rearing indicator species."

Analysis of habitat for this species requires the use of criteria as suggested in Tables 17 and 18. "However, actual habitat preferences for the stonecat, including young of the year, should be measured. Analysis of areas of suitable habitat is patterned after the Washington Method as discussed under spawning. Six to nine areas which are likely habitat for the proper indicator species are selected and four transects established over the area. The same procedure is followed in the construction of composite maps to determine the area of optimum habitat at five different discharges. The minimum rearing habitat is defined at 75 percent of the optimum habitat, as described under the section on spawning."

Suggested criteria for riffle productivity are those areas which have rubble bottoms (bed materials greater than 6 cm in diameter) with the depth range for optimum production between 8 and 23 cm. "The velocity criterion for optimum productivity is recommended to be the range of 30 to 46 cm/sec. Analysis of riffle production is on the basis of the optimum area available at a given discharge and is determined according to the graphical method as described above. Six to nine areas of riffle are selected according to bottom type, and four cross sections are established at equal intervals for the length of the riffle. Depth and velocity measurements are then made at 0.5 meter intervals (velocity measured at 0.6 total depth). [These data are] then plotted on separate planimetric maps, as above, for at least five separate discharges. A composite map detailing the area of optimum productivity for each discharge is then compiled and analyzed planimetrically. The minimum productivity habitat is defined as 75 percent of the optimum as determined by the discharge-optimum area curve."

"The minimum discharge for riffle productivity is then compared with the minimum discharge recommendation for the rearing habitat indicator species. Whichever discharge is greater is defined as the minimum recommended discharge. This is termed an overriding consideration."

### Idaho Method
(White and Cochnauer, 1975)

The only methodology which has been developed exclusively for the large-river

Table 16. Spawning requirements and fecundity of selected species of fish of the Northern Great Plains Region. Numbers following species' names refer to month(s) of spawning activity.

| Species | Cover | Substrate (type) | Depth (meters) | Velocity (cm/sec) | Temperature (°C) | Fecundity eggs/fish (max) |
|---|---|---|---|---|---|---|
| Brook trout (9-10) | X | Gravel | .15 | 15 - 91 | 3 - 7 | 2,000 |
| Brown trout (10-12) | X | Gravel | .15 | 40 - 52 | 6 - 13 | 6,000 |
| Rainbow trout (4-7) | X | Gravel | .15 | 43 - 82 | 7 - 13 | 6,000 |
| Creek chub (3-6) | | Gravel | ND | 49 - 91 | ND | 4,000 |
| Smallmouth bass (5-6) | X | Sand-rubble | 0.9 - 1.8 | 11 | 15 - 18 | 35,000 |
| Largemouth bass (5-6) | X | Root-debris | 0.3 - 1.8 | Still | 16 - 18 | 35,000 |
| Bluegill (5-7) | X | Firm sand | 0.3 - 1.2 | Still | 16 - 20 | 30,000 |
| White crappie (5-6) | | NA | 0.6 - 2.5 | Still | 15 - 18 | 15,000 |
| Black crappie (5-6) | | NA | 0.2 - 6.0 | Still | 15 - 18 | 25,000 |
| Black bullhead (5-7) | | Mud-sand | 0.6 - 1.2 | Still | 24 - 27 | 8,000 |
| Yellow bullhead (5-7) | | Mud-sand | 0.3 - 1.2 | Still | 24 - 27 | 6,500 |
| Channel catfish (5-7) | X | NA | NA | NA | 24 - 27 | 8,000 |
| Shovelnose sturgeon (est) (5-7) | | Rubble | 0.3 - 0.9 | 75 - 150 | ND | ND |
| Paddlefish (est)(5-7) | | Gravel | Variable | 49 - 91 | 16 | 250,000 |
| Longnose sucker (4-6) | | Gravel | 0.2 - 0.3 | 31 - 45 | 5 | 100,000 |
| White sucker (4-6) | | Gravel | 0.2 - 0.3 | 31 - 45 | 10 | 100,000 |
| Shorthead redhorse (4-5) | | Gravel | 0.3 - 0.9 | 31 - 61 | ND | 27,000 |
| Northern pike (3-5) | | Marsh grass | ND | Still | 9 - 11 | 100,000 |
| Golden shiner (5-8) | | Vegetation | ND | Still | ND | ND |
| Carp (5-7) | | Detritus | .15 | Still | 14 - 17 | 500,000 |
| Sand shiner (6-8) | | Sand | ND | ND | 24 - 27 | 800 |
| Fathead minnow (5-8) | X | Variable | .03 - 0.6 | Still | 16 | 3,000 |
| Longnose dace (5-6) | | Gravel | .03 - 0.3 | 15 - 45 | ND | 4,000 |
| River carpsucker (5-7) | | Debris | .15 | Still | 15 - 17 | 150,000 |
| Smallmouth buffalo (5) | | Variable | .15 | Still | 16 - 18 | 600,000 |
| Yellow perch (4-5) | | Variable | 1.5 - 3.1 | Still | 16 - 18 | 40,000 |
| Walleye (4-5) | | Gravel | 1.2 - 1.5* | 0 - 50 | 9 | 100,000 |
| Sauger (4-5) | | Gravel | 1.2 - 1.5* | 0 - 50 | 6 | 100,000 |

*Estimated optimum depth based on egg survival.

ND = not determined; NA = not applicable.

Source: Bovee, 1975.

Table 17. Distribution of stream fishes according to depth of water.

| Depth in meters<br>Depth in feet () | .15<br>(.5) | .31<br>(1) | .61<br>(2) | .91<br>(3) | 1.2<br>(4) | 1.5<br>(5) | 1.8<br>(6) | 2.1<br>(7) | 2.5<br>(8) |
|---|---|---|---|---|---|---|---|---|---|
| Species | | | | | | | | | |
| Stonecat | X | X | | | | | | | |
| Longnose dace | X | X | | | | | | | |
| Sand shiner | X | X | | | | | | | |
| Burbot (est) | X | X | X | | | | | | |
| Creek chub | X | X | X | | | | | | |
| Pearl dace | X | X | X | | | | | | |
| Shorthead redhorse | X | X | X | | | | | | |
| Emerald shiner | X | X | X | X | | | | | |
| Fathead minnow | X | X | X | X | X | X | | | |
| Flathead minnow | X | X | X | X | X | X | X | X | X |
| Longnose sucker | X | X | X | X | X | X | X | X | X |
| White sucker | X | X | X | X | X | X | X | X | X |
| Black bullhead | | X | X | X | X | X | X | X | X |
| Yellow bullhead | | X | X | X | X | X | X | X | X |
| Channel catfish | | X | X | X | X | X | | | |
| Rainbow trout | | X | X | X | X | | | | |
| Brown trout | | X | X | X | X | | | | |
| Smallmouth bass | | X | X | X | X | | | | |
| Rock bass | | | X | X | X | | | | |
| Northern pike | | | X | X | X | X | X | X | X |
| Plains minnow | | | X | X | X | X | | | |
| Silvery minnow | | | X | X | X | X | | | |
| Golden shiner | | | X | X | X | X | X | X | X |
| Brassy minnow | | | | X | X | X | | | |
| Largemouth bass | | | | X | X | X | X | X | X |
| Bluegill | | | | X | X | X | X | X | X |
| Green sunfish | | | | X | X | X | X | X | X |
| Pumpkinseed | | | | X | X | X | X | X | X |
| White crappie | | | | X | X | X | X | X | X |
| Black crappie | | | | X | X | X | X | X | X |
| Carp | | | | X | X | X | X | X | X |
| River carpsucker | | | | X | X | X | X | X | X |
| Smallmouth buffalo | | | | X | X | X | X | X | X |
| Yellow perch (est) | | | | | | X | X | X | X |
| Bigmouth buffalo | | | | | | | X | X | X |
| Walleye | | | | | | | | X | X |
| Sauger | | | | | | | | X | X |

Source: Bovee, 1975.

Table 18. Distribution of stream fishes according to stream velocity.

| Bottom material<br>Size range (mm)<br>Fall velocity (cm/sec)<br>(ft/sec) | Rubble<br>30<br>150<br>5 | Gravel<br>5-30<br>40-150<br>1.3-5 | Sand<br>.5-5<br>5-40<br>.6-1.3 | Silt<br>.05-.5<br>.5-5<br>.06-.6 | Mud<br>.05<br>.5<br>0-.06 |
|---|---|---|---|---|---|
| Species | | | | | |
| Stonecat | X* | X | | | |
| Flathead chub | X | X | X | X | X |
| Burbot | X | X* | | | |
| Longnose dace | X | X | | | |
| Shovelnose sturgeon | | X* | X | | |
| Sturgeon chub | | X | | | |
| Shorthead redhorse | | X | X | | |
| Blue sucker | | X | X | | |
| Smallmouth bass | | X | X* | | |
| Rock bass | | X | X* | | |
| Rainbow trout | | X | X* | | |
| Channel catfish | | X | X* | X | X |
| Longnose sucker | | X | X | X | X |
| White sucker | | X | X | X | X |
| Brook trout | | | X | | |
| Brown trout | | | X | | |
| Creek chub | | | X | | |
| Pearl dace | | | X | | |
| Emerald shiner | | | X | | |
| Sand shiner | | | X | | |
| Plains minnow | | | X | X | |
| Brassy minnow | | | X | X | |
| Silvery minnow | | | X | X | |
| Northern pike | | | X | X | X* |
| Walleye | | | X | X | X* |
| Black bullhead | | | | X | X* |
| Yellow bullhead | | | | X | X* |
| Golden shiner | | | | X | X* |
| Smallmouth buffalo | | | | X | X* |
| Yellow perch | | | | X | X* |
| Sauger | | | | X | X* |
| Carp | | | | X | X* |
| River carpsucker | | | | | X |
| Largemouth bass | | | | | X |
| Bluegill | | | | | X |
| White crappie | | | | | X |
| Black crappie | | | | | X |

*Indicates preferred range if species found in more than one habitat.

Source: Bovee, 1975.

environment is the Idaho Method. However, it is similar to the Bovee Method in that it employs the usable width analysis and was developed using warmwater indicator species. The methodology is based on predicting loss of habitat at reduced discharge and relating the predicted loss to physical and biological requirements of key fish species. It uses the Bureau of Reclamation's Water Surface Profile (WSP) computer program and requires only one set of field observations. The WSP program allows the investigator to examine specific portions of a cross section for suitability in meeting the needs of a species for a particular biological activity.

## Field Data

Field methods are discussed below.

Equipment list includes the following: (1) map, (2) camera and film, (3) depth rod, (4) tape measure, (5) current meter, (6) waders and (7) data forms.

Field data should be collected at the lowest practical discharge and should include (from White and Cochnauer, 1975) the following:

"1. Map showing stream reach being studied and the cross section locations.

"2. Photographs of stream reach being studied and of each cross section location.

"3. Description of bank and overbank material and vegetation (trees, brush, grass, logs).

"4. Cross sectional survey data including

a. total width (water surface)

b. depth profile

c. distance from shore-water intercept to each depth measurement

d. velocity (for determining discharge)

"5. Description of stream bottom materials along each cross section.

"6. Identification of points where streambed material and vegetation change within the cross section.

"7. Distance between cross sections.

"8. Measured flow in cubic feet per second and the corresponding water surface elevations at each cross section.

"Maps, photographs and descriptions of bank and overbank material are used by the hydrologist as part of the evaluation process.

"Cross-sectional survey data provide the core information from which changes in habitat are predicted. The specific characteristics of the study section determine the number of cross sections needed.

"For accurate predictions, a minimum of four and a maximum of 100 cross sections are needed for each study reach. In establishing cross sections it is important that the transect be located at right angles to the streamflow. In addition to those cross sections taken in areas of representative habitat suitable for one or more of the biological activities of fish species for which flows are being recommended, cross sections must also be taken at each flow control section in the study reach. When islands are located within a study reach, cross sections should be taken upstream and downstream from the island and where each channel around the island begins and ends. If a bridge is included in the study reach, cross sections should be established at the site and approximately 15 m (50 ft) above and below the bridge. If other controls such as log or debris jams are within the study reach, cross sections should be established 15 m (50 ft) above and below these controls [see Figure 29].

"The frequency of the depth measurements along a transect varies depending upon the purpose of data acquisition and the channel configuration. For discharge measurements in large rivers, depth is measured with sounding equipment at 3-m (10-ft) intervals along the

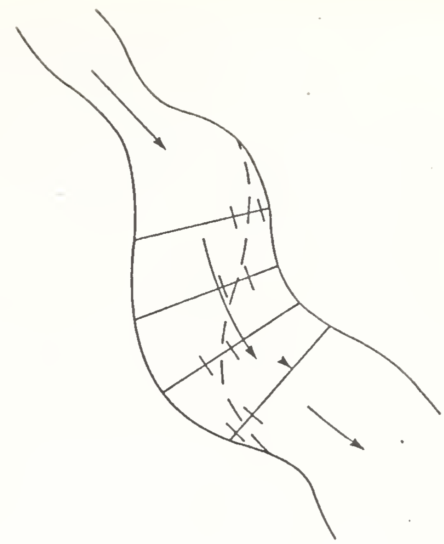


Figure 29. Location of transects for passage flow requirement evaluation. Broken line represents shallowest course as used in Oregon Method. Brackets on linear transects indicate partitioned segments (from White and Cochnauer, 1975).

transect. Standard U.S. Geological Survey methods should be followed. For other transects the distance between depth measurements may vary as long as sufficient measurements are taken to provide an adequate description of the channel profile.

"Because of the predictive capacity of the model, velocity measurements are not required except for calculating discharge. However, it is useful to have some velocity data, particularly in those portions of a transect which are critical for passage or spawning. These data can be used to evaluate the accuracy of predicted velocities. Velocity measurements are taken with a direct readout current meter using standard U.S. Geological Survey criteria.

"Substrate description is important both for use by the hydrologist in determining roughness coefficients and for evaluating habitat. Substrate particle size is defined as: sand-silt <2.5 mm (0.1 in) diameter; gravel = 2.5-73.7 mm (0.1-2.9 in) diameter; cobble (smooth) or rubble (angular) = 76.2-304.8 mm (3-12 in) dimaeter; boulder >304.8 mm (12 in) diameter; and bedrock. Predominant substrate composition is estimated and categorized by the observer. Where visual observations are not possible, depth soundings will facilitate evaluation of bottom composition.

"The basic program is designed for study reaches no greater than 9,999.9 units (m or ft)

in length, but adjustments can be made to accommodate greater distances. Measured distance between cross sections should represent, as near as possible, the distance along the line of flow or thalweg. This can be approximated by shoreline distance except for meanders or stream bends which should be measured along the inside and outside edges.

"At least one flow measurement must be made when taking field data (unless a gaging station is within the study reach) and must be identified with the water surface elevation at each cross section. Since all cross sections within a study reach may not be measured on the same day, and consequently at the same discharge, water surface elevations should be marked at each cross section location so that these elevations can be identified with the measured discharge. Although not necessary, it is also useful to identify high water marks and tie them into the cross section. This will give another set of elevations to firm up the field data and to help determine the proper energy slope of the specific stream reach being studied. If the discharge changes at some point within the study reach, such as a diversion or tributary inflow, the program has the capability of making adjustments for this if discharge measurements are available. However, for simplicity these kinds of areas should be avoided if possible.

"The quality of field data determines the accuracy of computed results. If elevations are taken within $\pm 3$ cm (0.1 ft), the predicted water surface elevations will be within $\pm 3$ cm (0.1 ft). The most important aspect of field data collection is consistency. Cross sections should originate from the same side of the stream; left and right streambanks should be identified (left bank is defined as being left when looking downstream); and cross sections should be taken progressing in a consistently upstream or downstream order. One person should work with the surveying instrument. In general, good surveying techniques must be used.

"After field data are collected, individual cross sections are plotted. Plots should include identification of streambed material, types of vegetation on overbank, left and right streambank and subsections to be analyzed for meeting biological criteria of fish species. Cross sections need not contain an equal number of subsections but are limited to a maximum of nine.

Data Processing

"Field data are reviewed with the hydrologist, keypunched and edited. Roughness coefficients are determined from field data, observations, photographs, and good hydraulic handbooks. An energy slope is computed from the streambed thalweg and observed water surface elevations. As previously pointed out, these observed water surface elevations must be tied to the specific streamflow measured at those elevations.

"These data are run through the water surface profile program which analyzes them from the most downstream cross section through the most upstream cross section, using an energy balance computation.

"The model is calibrated to the stream section by examining the output for the observed flow to determine if predicted water surface elevations match observed values. Adjustments in roughness coefficients ("n" values), cross sections, and station distances are made to bring predicted values within $\pm 3$ cm (0.1 ft) of observed values. After these calibrations have been made, a series of flows including the observed historic low flow and/or mean historic low flow for the time period of interest are selected and analyzed by the program.

Computer Output

"Available output from the program includes specific data on each cross section and summary tables of predictions for all flows analyzed. Specific cross-sectional output includes discharge, water surface elevation and slope at each cross section and mean velocity, conveyance area, top width and hydraulic radius for the cross section as a whole and for each subsection examined. From these data, wetted perimeter can be calculated and point depths determined [Figure 30]. Summary tables are printed and include water surface elevations, velocities, discharges, roughness coefficients and main channel distances.

Application of Proposed Methodology to the Snake River

"General field data requirements for predicting channel morphometry and hydraulic characteristics of streams at specified flows were described above. The next step is to define general study sites which will provide meaningful data relative to meeting the ecological requirements of select fish species and to describe how these data can be used in recommending stream resource maintenance flows.

"Three key fish species inhabiting the Snake River have been identified by Idaho Department of Fish and Game as species which

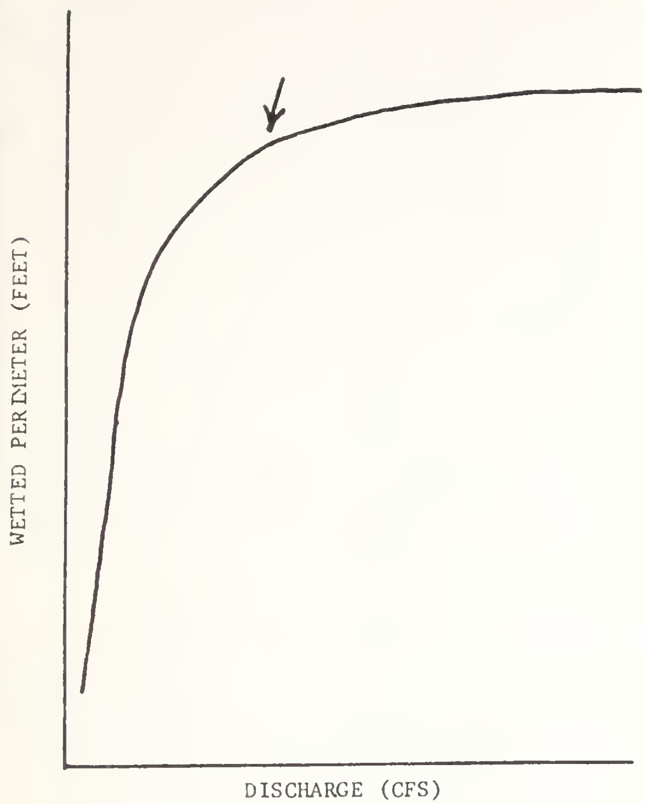



Figure 30. General representation of the wetted perimeter-discharge relationship. Arrow approximates the recommended rearing discharge (from White and Cochnauer, 1975).

must be accommodated by the recommended flows. These include white sturgeon (Acipenser transmontanus), smallmouth bass (Micropterus dolomieui), and channel catfish (Ictalurus punctatus). The proposed methodology requires that flow recommendations meet needs of fish species for biological activities related to passage, spawning, and rearing.

"Study areas are selected after thorough reconnaissance of the river segment for which stream resource maintenance flows are to be recommended. Study reaches should include representative habitat types which can be evaluated for passage, spawning, and rearing of key fish species.

"Passage. Channel catfish have been reported to migrate long distances (Scott and Crossman, 1973) while smallmouth bass (in the Snake River) are rather sedentary (Munther, 1967, 1970). Neither species is confined to large river systems in distribution and each is adaptable to a wide range of flows. The white sturgeon, however, inhabits only large rivers. Historically, this species was anadromous in the Snake River and therefore has well developed migratory behavior. Flows suitable for passage of white sturgeon should also accommodate smallmouth bass and channel catfish.

"Unfortunately, little is known about the extent of movement in the present land-locked white sturgeon population or about specific requirements for passage or for other biological activities. Mr. John Coon, Graduate Student, University of Idaho, is conducting a comprehensive ecological study of white sturgeon in the middle Snake River, the results of which will provide valuable input into establishing criteria for use in recommending stream resource maintenance flows. Prior to completion of this study, certain assumptions and inferences drawn from the literature must suffice in developing flow recommendations.

"A spawning migration of land-locked white sturgeon in the Snake River is assumed to occur, but its extent is unknown. Little movement was documented by Coon (1974) for small sturgeon <1.1 m (3.5 ft) in the middle Snake River while sturgeon greater than 1.8 m (6 ft) in length were observed to be quite mobile. Large individuals showed movements covering a succession of two or three holes in a 0.8 km (0.5 mi) section of river, within a 2-day period; constant up- or downstream movement of as much as 4.8 km (3 mi) was also observed. Such movement may be necessary for large sturgeon to obtain an adequate food supply. Based upon this information, passage becomes an important consideration throughout much of the year.

"To evaluate passage, shallow riffles or sandbars which would possibly impede up- or downstream movement are located. Since these areas will probably not be located at right angles to the flow, a varying number of transects will be needed to describe a potential passage block [Figure 29]. One depth profile along the shallowest course of the riffle or bar should be made. This information will be useful in final analysis and in determining the location and number of transects needed. For analysis, the shallow area of each transect is partitioned from the remainder of the transect and depth and velocities predicted for the range of flows desired.

"Predicted depths and velocities of the critical segment of each transect are then examined and channel characteristics are projected for the total nonlinear length of the potential passage block. From these projections, a minimum passage flow is recommended for those months in which sturgeon are active (mid-February to mid-November).

"The Oregon Method recommends a minimum flow for passage as one which creates a continuous portion of the cross section transect encompassing 10 percent of its total length (shallowest course) and which provides at least 25 percent of the total transect length suitable for passage of adult salmonids (Thompson, 1974). For paddlefish, Bovee (1974) recommends that 50 percent of the total transect length, as measured by the Oregon Method, meet clearance criteria with a continuous portion equalling at least 30 percent of the total transect length.

"Until flow criteria for passage of white sturgeon are determined, it is recommended that a minimum continuous depth of 1.5 m (5 ft) be maintained over 25 percent of the length of the potential block. Adjustments in these criteria will probably be necessary based upon field observations.

"Spawning. Smallmouth bass in the middle Snake River spawn from late May to early July with peak spawning activity between June 15 and July 1 (Keating, 1970). Nests are built over sand, gravel or rock substrate at depths of 0.6-6.1 m (2-20 ft) and spawning occurs when water temperature is between 12.8 and 20.0°C (55-68°F) (Scott and Crossman, 1973). Channel catfish spawn at temperatures ranging between 23.9 and 29.5°C (75-85°F) in secluded, semi-dark nests in holes, undercut banks, log jams, or rocks. Spawning probably occurs in the Snake River in August.

"Stable flow during the spawning and incubation period of smallmouth bass and channel catfish is probably more important for spawning success than recommending a specific stream resource maintenance flow for this activity.

"The spawning period of white sturgeon is reportedly May and June with spawning probably taking place over rocky substrate in swift current near rapids when water temperatures are between 8.9 and 16.7°C (48-62°F) (Scott and Crossman, 1973). These general requirements are similar to requirements reported for other sturgeon species of North America and Russia.

"Since there is nearly complete overlap in the time of spawning of white sturgeon and smallmouth bass, suitable discharge for white sturgeon spawning should also provide suitable spawning conditions for smallmouth bass. Field observations will be necessary to test the validity of this assumption. Although channel catfish spawn later than either of these species in the Snake River, rearing flows (which will be discussed later) will provide sufficient discharge for spawning.

"Since no specific information on the preferred location, depth, or velocity for successful spawning of white sturgeon has been reported, research should be initiated to determine physical requirements. However, until specific information becomes available, inferences of the spawning requirements can be made from known requirements of other species of sturgeon. The reliability of such comparisons is not known but is considered superior to no information at all. At least among Russian species of sturgeon, spawning requirements are very similar (Khoroshko, 1973).

"Most sturgeon literature examined reported that spawning occurs at the foot of a riffle or below a waterfall in swift water over rocky substrate. Unconfirmed accounts of sturgeon spawning in the Snake River suggest that white sturgeon spawn in similar habitat.

"Anadromous species of sturgeon native to Russia are reported to spawn at depths ranging from 1.5 to 5.0 m (5.0-16.4 ft) and at velocities of 0.7 to 1.1 mps (2.3-3.6 fps). Lake sturgeon, a smaller adfluvial species, is reported to spawn at depths ranging from 0.6-4.6 m (2.0-15.0 ft); no velocity requirements have been reported.

"Until spawning requirements of white sturgeon are documented, it is recommended that minimum depth criteria for spawning be set at 1.5 m (5 ft). This estimate appears within reason when one considers the large size of mature fish and that one female is accompanied by two or more males during the spawning act. A range of velocities from 0.6-1.1 mps (2.0-3.5 fps) is recommended.

"Transects for evaluating flow suitability for meeting spawning criteria should be established in representative reaches of the river as near the tail of riffles as physically practical for measurement. Areas of relatively uniform cross sectional profile would facilitate analysis but are not essential. At least three potential spawning riffles of comparable size should be examined in each study reach.

Field measurements are made and the data analyzed by the Water Surface Profile Program. At each of several predetermined discharges, those portions of the transects having suitable depths for spawning are partitioned and analyzed a second time for the purpose of determining velocity in these areas.

"Mean spawnable width of transects analyzed is determined for each discharge and the flow which provides maximum spawnable width is considered optimum. The minimum sustained discharge for spawning will be some specified percentage of this value and will be determined after original data analysis. The Oregon Wildlife Commission has set minimum sustained discharge at 80 percent of optimum for salmonids (Thompson, 1972), and Bovee (1974) recommends minimum discharge of 75 percent optimum for paddlefish. Optimum is defined as the maximum efficient flow for creating or maintaining suitable spawning areas.

"Rearing. Rearing requirements of fishes in general are less understood than requirements for other phases of the life cycle. Successful rearing of stream fishes depends upon adequate food supply, physical habitat and suitable water quality.

"Virtually nothing is known about the early life history of white sturgeon. Collection of larval white sturgeon and/or green sturgeon has been reported only once in the literature (Stevens and Miller, 1970). Catches in nets set at different depths give evidence that sturgeon larvae are demersal. The area of residence of white sturgeon smaller than 381 mm (15 in) in length is not known; large sturgeon inhabit deep pools.

"Sturgeon up to 482 mm (19 in) in length are reported to feed on plankton and small macroinvertebrates (Carlander, 1969). Scott and Crossman (1973) report that the diet of white sturgeon in this size range is predominantly chironomids (35.2 percent by volume) with lesser amounts of other aquatic insect larvae, crustaceans, and molluscs. Larger white sturgeon feed primarily on fish (48.6 percent by volume), crayfish, molluscs, and chironomid larvae. In general, sturgeon are omnivores and scavengers.

"Smallmouth bass habitat varies with fish size and season. Fingerlings rear in isolated pools, sloughs, and shallow stillwater areas. Adults inhabit shallow, still pools in spring; eddies, pools and slow runs in summer; and quiet rocky pools in late fall. In winter, they move into the substrate when water temperatures reach 6.7-7.8°C (44-46°F) (Munther, 1967, 1970). In the Snake River, food of fingerling smallmouth bass is reported to be predominantly aquatic insects (chironomid and mayfly) while crayfish make up 86 percent of the diet, by weight, of bass larger than 100 mm (4 in). The channel catfish is also a pool-associated species. Young feed primarily on aquatic insects and inhabit riffle or quiet pool environments. Adults usually inhabit deep water with sand, gravel or rubble bottom but may move into riffle areas at night to feed. Small channel catfish feed primarily on aquatic insect larvae while adults are omnivorous; crayfish constitute one of the more important food sources.

"All three species which stream resource maintenance flows must accommodate require pool-associated habitat for rearing. Also each has in common two food sources: aquatic insects and crayfish. Since invertebrate production takes place primarily in riffle areas and riffles are most affected by reduced discharge, it is reasoned that maintenance of suitable riffle conditions will also maintain suitable pool conditions.

"The USGS - Washington Department of Fisheries method for recommending rearing flows for Pacific Salmon species is based upon the assumption that rearing is proportional to food production, which is in turn assumed proportional to wetted perimeter (Collings, 1974). No studies have been reported which were specifically designed to determine the validity of this relationship. Although studies by Ruggles (1966) and Kennedy (1967) provide some insight into the relationship, more research is needed. Until better information is obtained, it is recommended that determination of rearing flows be patterned after the above method.

"In determining rearing discharge, several representative, physically accessible riffles are located, and one transect is established in each. Standard physical measurements are made and riffle characteristics predicted with the Water Surface Profile [WSP] program. Wetted perimeter is calculated and plotted against discharge.

"Starting at zero discharge, wetted perimeter increases rapidly for small increases in discharge up to the point where the river channel nears its maximum width. Beyond this inflection point, wetted perimeter increases slowly while discharge increases rapidly. The optimum quantity of water for rearing (food production) is selected near this inflection point" (Figure 30).

### Preparation of Recommended Flows

"After analysis of field data, recommended flows are assigned by month or 2-week period for each biological activity. The stream resource maintenance flow which is the highest for the critical biological activity of any given time period is the flow selected.

"Although the above approach does not take into consideration resident and/or anadromous salmonids, where these species are important, their flow requirements should be evaluated as part of the overall recommendation.

### Advantages and Disadvantages of Proposed Methodology

"The major advantage of the proposed methodology over those currently available is the reduced time involved in making field observations and consequently the reduced cost of determining stream resource maintenance flows. The initial expense for field equipment, however, is greater than for methodologies currently applied to wadable streams.

"A possible disadvantage of the methodology is that the accuracy may not be as good as would be obtained from actual field measurements. That is, the Water Surface Profile Program predicts mean values for hydraulic characteristics for each subsection (maximum of 9) within each transect. This is possibly less accurate than using actual field measurements taken at a series of reduced discharges, as is required by other methodologies employing field measurement. The weakest point in the application of the proposed methodology to the Snake River is the limited available information on certain ecological requirements of the fish species involved.

"This methodology is proposed only as a starting point for developing flow recommendations for a large river and is not intended to be rigid. It is based upon the best information available and with research and field experience will hopefully evolve into a sound approach to recommending stream resource maintenance flows for large rivers (and also smaller fluvial systems)."

### WSP (Water Surface Profile) Program

The WSP Program was developed in the 1960's by the U.S. Bureau of Reclamation for use in determining tailwater curves below a dam and backwater curves upstream from a dam. Since it has the capabilities of generating a number of water surface elevations from one set of cross sectional transect data, it has been adapted to instream flow fisheries studies. The program can compute these data for up to 100 cross sections in one job.

Field methods for data gathering, from Stalnaker and Arnette (1976), are discussed below. Field data needed include:

1. Cross section transects. These may be measured in the manner described for the Tight or Sag-Tape Method with the number of partitions across the transect not to exceed nine.

2. Distance between cross sections (transects).

3. Measured discharge in cubic feet per second, if gaging station data are available, otherwise use transect data to compute discharge using $Q = V \times W \times D$.

4. Water surface elevations at all cross sections.

5. Description of the stream bottom at each cross section.

6. Description of bank and overbank material and vegetation.

7. Identification of points where streambed material, vegetation, and stream bank change within the cross sections.

"If elevations are taken within $\pm 0.1$ of a foot, the predicted water surface elevations will be within $\pm 0.1$ foot. Transects should be established at right angles to the stream flow. Distance between cross sections should be measured along the thalweg. Measurements should also be made at the inside and outside of stream meanders. Critical or control sections should be included as a cross section. Where specific information is desired (e.g., a spawning area, feeding area, or a resting area) include cross sections of that area (this program has partitioning capabilities).

"In order for the output to be of more use, specific segments of the stream cross sections should be identified. This will enable the user to get specific information for that segment. At least one velocity measurement should be made when taking the field data. This measurement must be identified with the water surface elevation at the time of measurements. The water surface elevations at the other cross sections should also be noted at the time velocity measurements are being taken. It is useful to also observe high water marks and tie them into

the cross sections. This will give another set of elevations to add to the field data and help determine the proper energy slope of the specific stream reach being studied.

"If log jams or debris dams are included in a study reach, cross sections should be taken above and below these areas. These areas will have some form of control for at least part of the study reach. When islands are included in a reach, cross sections should be taken upstream and downstream from the island and at the points where the channels around the island begin and end.

"Cross sections should originate from the same side of the stream. Left and right streambanks should be identified, and cross sections should be taken consistently in an upstream or downstream order.

"When field data collection is completed, the individual cross sections should be plotted. The scale used is not particularly important. These plots should include identification of streambed material, types of vegetation on overbank, and left and right streambank identification.

Available Output

"Available output from WSP includes specific data for each cross section and tabular summaries of data for all flows included. Specific cross section output includes water surface elevations, flow velocities, tractive force (amount of force exerted upon stream bottom), conveyance areas and widths, hydraulic radii, and discharges. The predicted values are based on and within the precision of the field data.

"From the output data, a water surface profile showing water surface elevations, thalweg, and cross section location (by station) is plotted. A rating curve for the most downstream section is also plotted."

The WSP Program has been used in Montana for studies on the Yellowstone River and has been proposed for use for rivers and streams in Idaho.

A complete description of the program, how to input data, and a copy of the program itself is on the computer files at WRRI, University of Wyoming.

## RESEARCH NEEDS

### Carrying Capacity Concept

All of the methodologies listed in this document will, if utilized correctly, yield answers. However, it has been virtually impossible to select one methodology over another based upon biological suitability and correctness. We can assume that the more streamflow data we have, the more site specific our species habitat criteria, the more "critical" the areas at which our hydraulic measures are made, the more baseline information which we have regarding a stream, the better will be the output (the instream flow recommendation) of our methodology. This general assumption may be correct. The Instream Flow Service Group has attempted to make the Incremental Method as biologically sensitive as possible through the development of weighted habitat criteria and electivity curves. However, it cannot yet be said that the method enables one to accurately predict the effects of flow alteration on fish standing crops and habitat carrying capacity.

The fallacy of the "state of the art" has been that no methodology, no matter how detailed, addresses the question of potential biological consequences. The "field" technique commonly used today is to develop a plot of a necessary habitat feature (i.e., spawning, passage, food-producing or rearing areas) versus discharge. The link here to the biota is through the application of species habitat criteria (i.e., depth-velocity-substrate criteria for a given life history stage of a species). Analysis of such a plot typically focuses on locating the peak of the habitat line ("optimum" flow) and then either taking a percentage of this "optimum" or finding the point at which habitat begins to decline most rapidly, and calling this the recommended "minimum" flow.

While such an approach typifies the "state of the art," its validity can be questioned. It is an easier matter, if time allows and suitable species habitat criteria exist, to define the "optimum" flow (the discharge which provides the maximum quantity of a given habitat type) than it is the "maintenance" flow (the minimum discharge required to maintain present population levels). In many cases, especially for the numerous high-mountain streams of Regions 2 and 3, the fish populations present are not limited by this "optimum" condition and, in terms of population size, are not adapted to it. Rather, it is the low, base-flow periods of late summer, fall, and winter which are limiting. Thus, during this critical period of the year, if the objective is to recommend an instream flow to maintain the population at its present level, concern should be directed to these "maintenance," not "optimum," flow levels.

The assumption made by all current methodologies is that if the habitat is maintained at some given level, the fish population will be maintained. This appears to be a valid assumption, but it raises the question of whether we are trying to maintain the habitat or the population. Of course, the population needs habitat. But if we do not know the relationship between the habitat and the population which X amount of habitat can support, it is impossible to recommend a maintenance flow for the population based solely upon available habitat.

What has been lacking, and has limited the validity of our instream flow recommendations, is the recognition of a carrying capacity concept, such as that used in range management. A plot of habitat versus flow is a convenient way to summarize the losses and gains as discharge changes, but until we begin to investigate carrying capacity, we cannot say what this will mean in terms of the population. It is encouraging to see that the IFG is now initiating research in this area regarding the Incremental Method. Also, the Water Resources Research Institute (WRRI) at the University of Wyoming is involved in a similar effort.

### Winter Habitat Studies

Although some work has been done by researchers investigating the effects of winter conditions upon trout, there is still a great need for quantitative data in this area. Most of the studies that have been done concern food availability and utilization by trout during the winter (Kennedy, 1967; Maciolek and Needham, 1951; Reimers, 1963; Needham and Jones, 1957; Logan, 1967; Benson, 1955). Other information gathered about trout during the winter months includes trout fry mortality due to anchor ice formation (Benson, 1955); trout migration (Logan, 1967); trout mortality (Reimers, 1963; Needham and Jones, 1957); and water temperature tolerance and acclimation (Needham and Jones, 1957).

No researcher has yet defined the actual water depth, velocity, substrate, cover, or migration needs of trout in winter. None of the winter studies were done on streams which were completely frozen over while most streams in the Rocky Mountain region completely ice over during winter. It is probable that trout conditions and habits are different in iced-over streams than in streams which are at least

partially open during the winter. In addition, no data or information were found which could actually be used to evaluate, recommend, or determine the amount of water needed instream during winter months to maintain the existing fishery. Research is currently underway at the University of Wyoming WRRI regarding this subject.

### Incubation Flow Recommendations

Little work has been done specifically to determine incubation flows. Adequate flows for spawning are usually assumed to be adequate for incubation as well (Stalnaker and Arnette, 1976). The Oregon Department of Fish and Wildlife generally recommends an incubation flow of about two-thirds of the spawning flow, based upon field observations and experience (Thompson, 1972). Usually it is assumed flows are suitable for incubation as long as spawning redds have sufficient oxygen and water (Savage, 1962).

Intragravel rates of flow, exchange of flowing stream and gravel waters, temperatures, and dissolved oxygen levels are important factors of incubation flows (Stalnaker and Arnette, 1976). Data and techniques are available for establishing criteria for intragravel flows, temperatures, and dissolved oxygen levels (Wickett, 1954; Terhune, 1958; Hoppe and Finnell, 1970; Thompson, 1974). Stalnaker and Arnette (1976) give a good analysis of the "state of the art" concerning incubation flows and emphasize the fact that quantitative data are lacking regarding stream-gravel water flow exchange.

Thompson (1974) used 5.0 ppm intragravel dissolved oxygen as the basic criterion for incubation flows in the Snake River. Additional work along this line should be done to establish criteria to further quantify intragravel flows, temperatures, and dissolved oxygen levels for salmonid incubation flows. Sams and Pearson (1963) found higher permeability in spawning gravel that was wetted throughout the year. Future studies should be undertaken to determine any other differences between spawning areas which are wetted throughout the year and areas wetted only part of the year. Investigations into the hydrology of flowing stream and gravel water exchange should be conducted, as practically no data of this type exist. A need exists for all types of incubation flow data for non-salmonid species, as all incubation flow work done to date pertains only to salmonids.

It is encouraging that research in the area of incubation requirements for salmonids is currently underway at the University of Idaho.

### Habitat Criteria for Non-Salmonid Species

Numerous habitat criteria for the various life history phases of the salmonid family have already been developed. Such research, however, also must be conducted for the numerous important cool and warmwater species. The Instream Flow Group has attempted to locate, review and disseminate all available information, but many gaps in the data still exist.

### Flushing Flows

There is also a need for quantitative information about flushing flows. With the present "state of the art" it is unknown if flushing flows are necessary for maintaining stream quality. It is well-documented that sediment accumulation in streambeds is detrimental to salmonid spawning (Shalton and Pollock, 1966; Peters, 1962; Hobbs, 1937; Hall and Lantz, 1969) and invertebrate populations (Tebo, 1955; Gammon, 1970; Cordone and Kelly, 1961). If flushing flows are necessary to remove fines and maintain stream quality, methods for determining the proper magnitude, time duration, as well as the time of the year, should become a valuable part of the instream flow recommendations.

Little field data concerning flushing flows have been Collected. Eustis and Hillen (1954) reported a removal of 60 percent of deposited sediments by controlled releases of water from Granby Dam, Colorado. Apparently no follow-up data were collected to see if this flushing of sediments allowed declining aquatic invertebrate populations to recover. Hoppe and Finnell (1970) estimated flushing flows for "critical" habitat areas (such as spawning areas) in the Frying Pan River, Colorado. The resulting recommendation of a 48-hour flushing flow at the 17 percentile level is based upon both biological and physical data but is only for use in the Frying Pan River for specific habitat areas. The Tennant Method (Tennant, 1976) recommends 200 percent of the average flow as an adequate flushing flow for most streams, but apparently there is no data base to support this contention, as none is presented or mentioned.

How flushing flows affect trout spawning and invertebrate populations appear to be the most important factors to be considered. Flushing flows may also influence trout habitat by affecting such things as ice removal, fish passage, ice scouring, and streambed maintenance-redistribution. The two primary objectives of studies concerning flushing flows should be to discover how important flushing flows are to stream quality and to develop a methodology for recommending flushing flows for streams that are to be subjected to water development projects.

## LITERATURE CITED


Allen, K. R. 1959. The distribution of stream bottom faunas. Proc. New Zealand Ecol. Soc. 6:5-8.

Allen, K. R. 1969. Limitations on production in salmonid populations in streams, p. 3-18. In Symposium on Salmon and Trout in Streams, H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B. C.

Ambuhl, Von Heinz. 1959. The significance of flow as an ecological factor. Schweizerische Zeitschrift fuer Hydrologie, Vol. XXI Fasc. 2:133-270. (Translation by John DeWitt, Humboldt State College, Arcata, Calif.)

Anonymous. 1968. Guide for application of water surface profile computer program. U.S. Bur. Reclamation, Sedimentation Sect., Hydrology Branch, Denver, Colo. 17 pp. + exhibits.

Anonymous. 1976. HEC-2 water surface profiles. U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, Calif. 17 pp. + exhibits.

Bachmann, R. W. 1958. The ecology of four north Idaho trout streams with reference to the influence of forest road construction. Master's thesis, Univ. of Idaho. 97 pp.

Baldes, R. J., and R. E. Vincent. 1969. Physical parameters of microhabitats occupied by brown trout in an experimental flume. Trans. Amer. Fish. Soc. 98:230-238.

Bardach, J. E., J. H. Ryther, and W. O. McLarney. 1972. Aquaculture, the farming and husbandry of freshwater and marine organisms. Wiley-Interscience, A Division of John Wiley and Sons, Inc., New York. 868 pp.

Bartsch, A. F. 1960. Settleable solids, turbidity, and light penetration as factors affecting water quality. Biological Problems in Water Pollution, Trans. 1959 Seminar. USDHEW, Cincinnati, Ohio. Tech. Rep. W60-3, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

Bartschi, Don K. 1976. A habitat-discharge method of determining instream flows for aquatic habitat. In Proc. Symp. and Spec. Conf. on Instream Flow needs, ed. J. F. Orsborn and C. H. Allman. Vol. II, pp. 285-294. Amer. Fish. Soc., Bethesda, Md.

Bayha, Keith. 1978. Instream flow methodologies for regional and natioanl assessments. Instream Flow Information Paper No. 7. FWS/OBS-78/61. 97 pp.

Bell, M. C. 1973. Fisheries handbook of engineering requirements and biological criteria. Fisheries-Engineering Research Program, Corps of Engineers, North Pacific Division. Portland, Oregon.

Benson, N. G. 1953. The importance of groundwater to trout populations in the Pigeon River, Michigan. Trans. 18th N. Amer. Wild. Conf. pp. 268-281.

Benson, N. G. 1955. Observations of Anchor Ice in a Michigan Trout Stream. Ecology 36:529-530.

Binns, N. A. 1976. Evaluation of habitat quality in Wyoming trout streams. Resume of a Paper presented at the Annual Meeting of the American Fisheries Society, Dearborn, Michigan, 1976. Wyoming Game and Fish Dept. mimeo report. Cheyenne, Wyo. 33 pp.

Binns, N. A. and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Trans. Amer. Fish. Soc. 108: 215-228.

Boaze, John L. and R. S. Fifer. 1977. Instream flow determination for the Hunter Creek drainage. U.S. Fish and Wildlife Service Report. Salt Lake City, Utah. 58 pp.

Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. J. Wildlife Mgt. 18:229-239.

Bovee, Ken D. 1974. The determination, assessment, and design of "instream value" studies for the northern Great Plains region. University of Montana. Final Report, Contract #68-01-2413, Environmental Protection Agency.

Bovee, Ken D. 1975. The determination, assessment, and design of "instream value" studies for the northern Great Plains region. University of Montana, Missoula. 205 pp.

Bovee, Ken D. 1978. The incremental method of assessing habitat potential for coolwater species, with management implications. Amer. Fish. Soc. Spec. Publ. 11:340-346.

Bovee, Ken D. 1978. Probability-of-use criteria for the Family Salmonidae. Instream Flow Information Paper No. 4. FWS/OBS-78/07. 80 pp.

Bovee, K. D., M. A. Carnevale and T. S. Hardin. 1979. A test of the PHABSIM model in southeastern Wyoming. Draft USFWS Report. CIFSG, Ft. Collins, Colo. 29 pp.

Bovee, K. D., and T. Cochnauer. 1977. Development and evaluation of weighted criteria--probability-of-use curves for instream flow methodologies. U.S. Fish Wildl. Serv. IFIP#3, Cooperative Instream Flow Service Group, Ft. Collins, Colo.

Bovee, K. D., and R. Milhous. 1978. Hydraulic simulation in instream flow studies: Theory and technique. Instream Flow Information Paper No. 5. FWS/OBS-78/33. 131 pp.

Brynildson, O. M., V. A. Hacker, and T. A. Klick. 1973. Brown trout, life history, ecology and management. Wisc. Dept. of Nat. Res. Publ. 234. 16 pp.

Butler, R. L., and V. M. Hawthorne. 1968. The reactions of dominant trout to changes in overhead artificial cover. Trans. Amer. Fish. Soc. 97:37-41.

Campbell, H. J. 1954. The effect of siltation from gold dredging on the survival of rainbow trout and eyed eggs in Powder River, Oregon. Oregon St. Game Comm., 3 pp. (processed)

Carlander, Kenneth D. 1969. Handbook of freshwater fishery biology. Vol. I. Iowa State University Press.
Chapman, D. W. 1962. Effects of logging upon fish resources of the west coast. Jour. Forestry 60(8):533-537.
Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. Amer. Natur. 100:345-357.
Chapman, D. W., and T. C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. pp. 153-176. In Symposium on Salmon and Trout in Streams, H. R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver, B. C.
Chrostowski, Henry P. 1972. Central Utah Project, stream habitat studies on the Uinta and Ashley National Forests. USDA Forest Service Report. Ogden, Utah. 149 pp.
Coble, D. W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Trans. Amer. Fish. Soc. 90:469-474.
Cochnauer, Tim. 1976. Instream flow techniques for large rivers. In Proc. Symp. and Spec. Conf. on Instream Flow Needs, ed. J. F. Orsborn and C. H. Allman. Vol. II, pp. 387-399. Amer. Fish. Soc., Bethesda, Md.
Collings, Mike. 1972. A methodology for determining instream flow requirements for fish. In Proceedings of Instream Flow Methodology Workshop. Washington Dept. of Ecology. Olympia, Wash. pp. 72-86.
Collings, M. R. 1974. Generalization of spawning and rearing discharges for several Pacific salmon species in western Washington. USGS, Open File Report. 39 pp.
Collotzi, Albert. 1975. Aquatic habitat inventory computer storage program guidelines. USDA Forest Service Report. Bridger-Teton National Forest. 20 pp.
Coon, John. 1974. Effects of water development schemes on white sturgeon in the Middle Snake River. Progress Report for Coordinating Committee, Idaho Cooperative Fishery Research Unit.
Cooper, C. O., and T. A. Wesche. 1976. Stream channel modification to enhance trout habitat under low flow conditions. Water Resources Series No. 58. Water Resources Research Institute, Univ. of Wyo., Laramie. 170 pp.
Cooper, J. L. 1976. United States Forest Service stream survey procedure--Northern Region. In Proc. Symp. and Spec. Conf. on Instream Flow Needs, ed. J. F. Orsborn and C. H. Allman. Vol. II, pp. 300-313. Amer. Fish. Soc., Bethesda, Md.
Cooperative Instream Flow Service Group. 1979. Draft 3 year completion report. USFWS, Ft. Collins, Colorado. 168 pp.
Cordone, A. J., and D. W. Kelley. 1961. The influence of inorganic sediment on the aquatic life of streams. Calif. Fish and Game, 47:189-228.
Delisle, G. E., and B. E. Eliason. 1961. Stream flows required to maintain trout populations in the Middle Fork Feather River Canyon. Calif. Dept. Fish and Game, Water Projects Branch, Rept. No. 2, Appendix, 19 pp.
Dill, L. M. 1969. Fulton River fry quality and ecology program. Report of 1968 studies, Dept. of Fish. of Canada, Vancouver, B. C. 185 pp.
Dimond, J. B. 1967. Evidence that drift of stream benthos is density related. Ecology 48:855-857.
Dunham, Donald K., and Albert Collotzi. 1975. The transect method of stream habitat inventory--Guidelines and applications. USDA Forest Service. Ogden, Utah. 98 pp.
Egglishaw, H. J. 1964. The distributional relationship between the bottom fauna and plant detritus in streams. Jour. Animal Ecol. 33:463-476.
Elliott, J. M. 1967. Invertebrate drift in a Dartmoor stream. Arch. Hydrobiol. 63:202-237.
Ellis, M. M. 1944. Water purity standards for freshwater fishes. U.S. Fish and Wildl. Serv., Spec. Sci. Rept. 2, 18 pp.
Ellis, M. M., B. A. Westfall, and M. D. Ellis. 1946. Determination of water quality. U.S. Fish and Wildlife Serv., Res. Rept. 9, 122 pp.
Elser, A. A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Amer. Fish. Soc. 97(4):389-397.
Eriksen, C. H. 1966. Benthic invertebrates and some substrate-current-oxygen interrelationships. pp. 98-115. In Organism-Substrate Relationships in Streams, Spec. Publ. No. 4, Pymatuning Lab of Ecology. Univ. of Pittsburgh, Penn.
Eustis, A. B., and R. H. Hillen. 1954. Stream sediment removal by controlled reservoir releases. Progressive Fish-Culturist, Vol. 16, No. 1, January 1954, pp. 30-35.
Everest, F. H., and D. W. Chapman. 1972. Habitat selection and spatial interaction by Juvenile chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Bd. Canada, 29:91-100.
Gammon, J. R. 1970. The effect of inorganic sediment on stream biota. EPA, Water Quality Office, Water Poll. Control Research Series No. 18050 DWC 12/70.
Giger, R. D. 1973. Streamflow requirements of salmonids. Oregon Wildlife Commission, Job Final Report, Project AFS 62-1, 117 pp.

Good, W. R. 1974. Some effects of spring snowmelt runoff on aquatic invertebrate populations in a high mountain stream. Water Resources Series No. 50. Water Resources Research Institute, Univ. of Wyoming. Laramie, Wyoming. 103 pp.

Gorman, O. T. and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology, 59(3). pp. 507-515.

Greeley, J. R. 1932. Spawning habits of brook, brown, and rainbow trout and the problem of egg predators. Trans. Amer. Fish. Soc. 62:239-248.

Hall, J. D. and Richard L. Lantz. 1969. Effects of loging on the habitat of coho salmon and cutthroat trout in coastal streams. Symposium on Salmon and Trout in Streams, Univ. of British Columbia, Vancouver, B. C. 388 pp.

Hansen, E. A. 1975. Some effects of groundwater on brown trout redds. Trans. Amer. Fish. Soc. 104(1):100-110.

Hartman, G. F. 1962. Observations on behavior of juvenile brown trout in a stream aquarium during winter and spring. J. Fish. Res. Bd. Canada 20:769-787.

Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underlying coho salmon (Oncorhyncus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Bd. Canada, 22:1035-1081.

Hartman, G. F. 1969. Reproductive biology of the gerrard stock of rainbow trout. In Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B. C. pp. 53-67.

Hayes, F. R., J. R. Wilmot, and D. A. Livingstone. 1951. The oxygen consumption of the salmon egg in relation to development and activity. Jour. Exptl. Zool. 116:377-395.

Hazzard, A. A. 1932. Some phases of the life history of the eastern brook trout (Salvelinus fontinalis). Trans. Amer. Fish. Soc. 62:344-350.

Herrington, R. B., and D. K. Dunham. 1967. A technique for sampling general fish habitat characteristics of streams. USDA Forest Service, Res. Paper INT-41. Ogden, Utah. 12 pp.

Hill, William T., Jr. 1978. Determination of Manning's n for mountain streams. Unpublished M.S. thesis. Dept. of Civil Engr., Univ. of Wyoming, Laramie. 44 pp.

Hoar, W. S., M. H. A. Keenleside, and R. G. Goodall. 1957. Reaction of juvenile Pacific salmon to light. J. Fish. Res. Bd. Canada, 14:815-830.

Hobbs, Derisley F. 1937. Natural reproduction of Quinnat salmon, brown and rainbow trout in certain New Zealand waters. New Zealand Marine Dept., Fish. Bull. No. 6.

Hooper, D. R. 1973. Evaluation of the effects of flows on trout stream ecology. Dept. of Engineering Res. Pacific Gas and Electric Co., Emeryville, Calif. 97 pp.

Hoppe, R. A., and L. M. Finnell. 1970. Aquatic studies on Frying Pan River, Colorado--1969-1970. U.S. Bur. of Sport Fish. Wildl. Div. of River Basin Studies. Mimeo Report. 12 pp.

Hoppe, Richard A. 1975. Minimum streamflows for fish. Paper distributed at Soils-Hydrology Workshop, USFS, Montana State Univ., Jan. 26-30, 1976. Bozeman, Montana. 13 pp.

Hunt, R. L., 1969. Effects of habitat alteration on production, standing crops and yield of brook trout in Lawrence Creek, Wisconsin. Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver, B. C. pp. 281-312.

Hunt, R. L. 1976. A long-term evaluation of trout habitat development and its relation to improving management-related research. Trans. Amer. Fish. Soc. 105(3):361-365.

Hunter, J. W. 1973. A discussion of game fish in the state of Washington as related to water requirements. Rept. by Fish Mgt. Div. of Wash. St. Dept. of Game to Wash. St. Dept. of Ecology. 66 pp.

Interagency Task Force - Instream Flows. 1979. Guidelines for determining instream flow needs. Report prepared pursuant to Directive dated July 12, 1978, from the President of the United States. 21 pp.

Isaacson, J. Allen. 1976. Determining instream flows using the Sag Tape method and R-2 Cross X computer program. In Proc. Symp. and Spec. Conf. on Instream Flow Needs, ed. J. F. Orsborn and C. H. Allman. Vol. II, pp. 314-321. Amer. Fish. Soc., Bethesda, Md.

Jespersen, Dennis M. 1979. Instream flow determination and impact evaluation of water diversion on the Colorado River cutthroat trout and brook trout in the North Fork and Roaring Fork of the Little Snake River drainage. U.S. Forest Service Report. Medicine Bow National Forest, Laramie, Wyo. 109 pp.

Jespersen, Dennis M. 1980. Instream flow determination for streams affected by Stage I and II of the City of Cheyenne water development project in the Douglas Creek drainage and supplemental flow recommendations in the North Fork of the Little Snake River drainage. Draft U.S. Forest Service Report. Medicine Bow National Forest, Laramie, Wyo.

Kalleberg, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout (Salmo salar L. and S. trutta L.). Inst. Freshw. Res. Drottningholm, 39:55-98.

Kamler, E., and W. Riedel. 1960. A method for quantitative study of the bottom fauna of tartar streams. Polskie Archiwum Hydrogiologic, TQM VII (XXI).

Keating, James F. 1970. Growth rates and food habits of smallmouth bass in the Snake, Clearwater and Salmon Rivers, Idaho, 1965-67. Master's Thesis, Univ. of Idaho.

Kemp, H. A. 1949. Soil pollution in the Potomac River Basin. Amer. Water Works Assoc. Jour. 41(9):792-796.

Kendall, W. C. 1929. The fishes of the Cranberry Lake region. Roosevelt Wildl. Bull., Vol. 5, No. 2.

Kennedy, H. D. 1967. Seasonal abundance of aquatic invertebrates and their utilization by hatchery reared rainbow trout. U.S. Fish and Wildl. Ser., Bur. of Sport Fisheries and Wildlife, Technical Paper No. 12, Washington, D. C. 41 pp.

Khoroshko, P. N. 1973. Sturgeon reproduction in the Volga Basin. Hydrological Journal 9(1):27-33.

Kimble, L. A., and T. A. Wesche. 1975. Relationships between selected physical parameters and benthic community structure in a small mountain stream. Water Resources Series No. 55. Water Resources Research Institute, Univ. of Wyoming, Laramie, Wyoming. 65 pp.

Kraft, Melvin E. 1968. The effects of controlled dewatering on a trout stream. Master's Thesis, Montana State Univ., Bozeman.

Latta, W. C. 1969. Some factors affecting survival of young-of-the year trout (S. fontinalis Mitchell) in streams. In Symposium on Salmon and Trout in Streams, H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B. C.

Leitritz, E. 1969. Trout and salmon culture. Calif. Dept. of Fish and Game. Fish Bull. No. 107. 169 pp.

Lewis, Stephen L. 1967. Physical factors influencing fish populations in pools of a trout stream. Master's Thesis, Montana State Univ., Bozeman.

Lewis, S. L. 1969. Physical factors influencing fish populations in pools of a trout stream. Trans. Amer. Fish. Soc. 98:14-19.

Linsley, R. K., and J. B. Franzini. 1972. Water Resources Engineering, 2nd ed. McGraw-Hill Book Co., New York.

Linsley, R. K., M. A. Kohler, and J. L. H. Paulhus. 1975. Hydrology for engineers, 2nd edition. McGraw-Hill Book Company, New York. 482 pp.

Logan, S. L. 1967. Winter observations on bottom organisms and trout in Bridger Creek, Montana. Trans. Amer. Fish. Soc. 92:140-145.

Maciolek, J. A. and P. R. Needham. 1952. Ecological effects of winter conditions on trout and trout foods in Convict Creek, California, 1951. Trans. Amer. Fish. Soc. 81:202-217.

McNeil, W. J. 1964. Effects of the spawning bed environment on reproduction of pink and chum salmon. U.S. Fish and Wildlife Service, Fish. Bull. 65(2):495-523.

McNeil, W. J., and W. H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service Special Scientific Reprint. Fish. No. 469.

Mills, D. H. 1971. Salmon and trout, a resource, its ecology and management. St. Martin's Press, Inc., New York. 351 pp.

Mundie, J. H. 1969. Ecological implications of the diet of juvenile coho in streams. pp. 135-152. In Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B. C.

Munther, Gregory L. 1967. Movement and distribution of smallmouth bass in the Middle Snake River. Master's Thesis, Univ. of Idaho.

Munther, Gregory L. 1970. Movement and distribution of smallmouth bass in the Middle Snake River. Trans. Am. Fish. Soc. 99(1):44-53.

Neave, F., and G. C. Carl. 1940. The brown trout on Vancouver Island. Sixth Pac. Sci. Cong. Vol. 3., pp. 341-343.

Needham, P. R. 1934. Quantitative studies of stream bottom foods. Trans. Amer. Fish. Soc. 64:238-247.

Needham, P. R. and A. C. Jones. 1959. Flow, temperature, solar radiation, and ice in relation to activities of fishes in Sagehen Creek, California. Ecology 40(3):465-474.

Needham, P. R., and R. Usinger. 1956. Variability in the macrofauna of a single riffle in Prosser Creek, California as indicated by a Surber sampler. Hilgardia 24:383-409.

Nelson, F. A. 1980. Evaluation of four instream flow methods applied to four trout rivers in southwest Montana. Draft Montana Dept. of Fish Wildlife and Parks Report to USFWS. Contract No. 14-16-0006-78-046. 105 pp.

Newman, M. A. 1956. Social behavior and inter-specific competition in two trout species. Physiol. Zool. 29:64-81.

Nickelson, Thomas E. 1976. Evaluation of stream habitat for coho salmon. In Proc. Symp. and Spec. Conf. on Instream Flow Needs, ed. J. F. Orsborn and C. H. Allman. Vol. I, pp. 532-533. Amer. Fish. Soc., Bethesda, Md.

Nickelson, Thomas E., and R. E. Hafele. 1978. Streamflow requirements of Salmonids. Annual Progress Report by Oregon Dept. of Fish and Wildlife to USFWS. Contract No. 14-16-0001-77-538. 26 pp.

Northern Great Plains Resource Program. 1974. Instream needs sub-group report. Work Group C. Water. 35 pp.

Odum, E. P. 1959. Fundamentals of ecology. 2nd edition. W. B. Saunders Co., Philadelphia and London. pp. 88-89.

Pautzke, C. F. 1938. Studies on the effect of coal washings on steelhead and cutthroat trout. Trans. Amer. Fish. Soc. 67:232-233.

Pearson, L. S., K. R. Conover, and R. E. Sams. 1970. Factors affecting the natural rearing of juvenile coho salmon during the summer low flow season. Unpublished manuscript. Fish. Comm. of Oreg., Portland, Oregon. 64 pp.

Pennak, R. W., and E. D. Van Gerpen. 1947. Bottom fauna production and physical nature of the substrate in a northern Colorado trout stream. Ecology 28(1):42-48.

Peters, J. C. 1962. The effects of stream sedimentation on trout embryo survival. In Biological Problems in Water Pollution, Third Seminar, 1962. pp. 275-279. Pub. Health Serv. Publ. 999-WP-25.

Peters, J. C., and W. Alvord. 1964. Man-made channel alterations in thriteen Montana streams and rivers. Transactions of North America Wildlife Conference, 29:93-102.

Prewitt, C. G. and C. A. Carlson. 1977. Evaluation of four instream flow methodologies used on the Yampa and White Rivers, Colorado. Colorado State Univ. Report to USFWS. Contract No. YA-512-CT6-1BLM. 96 pp.

Pruitt, T. A. and R. L. Nadeau. 1978. Recommended stream resource maintenance flows on seven southern Idaho streams. Instream Flow Information Paper No. 8. FWS/OBS-78/68. 60 pp.

Reimers, N. 1957. Some aspects of the relation between stream foods and trout survival. Calif. Fish and Game 43:43-69.

Reimers, N. 1963. Body condition, water temperature, and over-winter survival of hatchery-reared trout in Convict Creek, California. Trans. Amer. Fish. Soc. 92(1):39-46.

Reiser, D. W., and T. A. Wesche. 1977. Determination of physical and hydraulic preferences of brown and brook trout in the selection of spawning locations. Water Resources Series No. 64. Water Resources Research Institute, Univ. of Wyoming, Laramie, Wyoming. 112 pp.

Rose, K. L. and C. D. Johnson. 1976. The relative merits of the modified sag-tape method for determining instream flow requirements. Draft USFWS Report. Salt Lake City, Utah. 26 pp.

Ruggles, C. P. 1966. Depth and velocity as a factor in stream rearing and production of juvenile coho salmon. Canadian Fish Culturist 38:37-53.

Russell, R. L., and R. J. Mulvaney. 1973. Recommending streamflows to meet national forest needs. In Proc. Hydrology and the Environment Seminar. Water Resources Res. Inst., Univ. of Wyoming, Laramie, pp. 32-52.

Ruttner, F. 1953. Fundamentals of limnology (Translation by D. G. Frey and F. E. J. Fry). Univ. Toronto Press. xi + 242 pp.

Sams, R. E., and L. S. Pearson. 1963. A study to develop methods for determining spawning flows for anadramous salmonids. Oregon Fish Commission, Portland. 56 pp. (unpublished)

Saunders, J. W., and M. W. Smith. 1962. Physical alteration of stream habitat to improve brook trout production. Trans. Amer. Fish. Soc. 91:185-188.

Savage, J. L. 1962. Methods used in salmon spawning area surveys. In Minutes of the Second Annual Meeting Calif. Dept. Fish and Game Water Projects and Pollution Conf. pp. 20-39.

Scott, D. 1958. Ecological studies on the Trichoptera of the River Dean, Cheshire. Arch. Hydrobiol. 54:340-392.

Scott, W. F., and E. J. Crossman. 1973. Freshwater fishes of Canada. Bull. 184, Fish. Res. Bd. Canada.

Shelton, J. M. and R. D. Pollock. 1966. Siltation and egg survival in incubation channels. Trans. Amer. Fish. Soc. 95(2).

Shetter, D. S., O. H. Clark, and A. S. Hazzard. 1946. The effects of deflectors in a section of Michigan trout streams. Trans. Amer. Fish. Soc. 76:248-278.

Shumway, D. L., C. E. Warren, and P. Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Trans. Amer. Fish. Soc. 93(4):342-356.

Silvey, Lee. 1976. R-2 Cross program: A sag-tape method of channel cross section measurement for use with instream flow determination. USDA Forest Service, Region 2. Lakewood, Colorado, 34 pp.

Smith, A. K. 1973. Development and application of spawning velocity and depth criteria for Oregon salmonids. Trans. Amer. Fish. Soc. 102:312-316.

Smith, George L. (ed.). 1979. Proceedings of Workshop in instream flow habitat criteria and modeling. Colorado Water Resources Research Institute Information Series No. 40. Colorado State Univ., Ft. Collins. 244 pp.

Sprules, W. M. 1947. An ecological investigation of stream insects in Algonquin Park, Ontario. Univ. Toronto Studies, Biol. 56, Pub. Ont. Fish. Res. Lab. 69: 1-81.

Stalnaker, C. B., and J. L. Arnette. 1976. Methodologies for the determination of stream resource maintenance flow requirements: An assessment. Western Water Association, Office of Biological Service, U.S. Fish and Wildlife Service. U.S. Dept. of the Interior, Washington, D. C. 199 pp.

Stevens, Donald E., and Lee W. Miller. 1970. Distribution of sturgeon larvae in the Sacramento-San Joaquin River system. California Fish and Game 56(2):80-86.

Stuart, T. A. 1953. Spawning migration, reproduction and young stages of loch trout (S. trutta). Fresh. and Sal. Fish. Res. Home Dept., Scotland. Rept. No. 5. 39 pp.

Swank, G. W. 1975. Preliminary summary of R-6 instream flow analysis. Draft Forest Service Report. Portland, Oregon. 10 pp.

Swank, Gerald W., and Robert W. Phillips. 1976. Instream flow methodology for the Forest Service in the Pacific Northwest region. In Proc. Symp. and Spec. Conf. on Instream Flow Needs, ed. J. F. Orsborn and C. H. Allman. Vol. II, pp. 334-343. Amer. Fish. Soc., Bethesda, Md.

Tarzwell, C. M. 1937. Experimental evidence on the value of trout stream improvement in Michigan. Trans. Amer. Fish. Soc. 66:177-187.

Tarzwell, C. M. 1938. An evaluation of the methods and results of stream improvement in the southwest. Trans. No. Amer. Wildl. Conf. 3:339-364.

Tarzwell, C. M. 1957. Water quality criteria for aquatic life. In Biological Problems in Water Pollution, USDHEW, Robert A. Taft Sanitary Engr. Ctr., pp. 246-272.

Tebo, L. B., Jr. 1974. Review of selected parameters of trout stream quality. In Symposium on Trout Habitat Research and Management. Proceedings. Appalachian Consortium Press, Boone, North Carolina, pp. 20-32.

Tennant, D. L. 1975. Instream flow regimens for fish, wildlife, recreation and related environmental resources. U.S. Fish and Wildlife Service Report. Billings, Mont. 18 pp.

Tennant, D. L. 1976. Instream flow regimens for fish, wildlife, recreation, and related environmental resources. In Proc. Symp. and Spec. Conf. on Instream Flow Needs, ed., J. F. Orsborn and C. H. Allman. Vol. II, pp. 359-373. Amer. Fish. Soc., Bethesda, Md.

Terhune, L. D. B. 1958. The Mark VI ground-water standpipe for measuring seepage through salmon spawning gravel. Journal Fish. Res. Bd., Canada 15(5):1027-1063.

Tessmann, Stephan A. Environmental Assessment. Technical Appendix E, in "Reconnaissance elements" of the western Dakotas region of South Dakota study. Water Resources Research Institute, South Dakota State University.

Tew, R. K., L. J. Schmidt, W. J. Elsea, H. Chrostowski, A. W. Collotzi and D. K. Dunham. 1977. Procedural guideline for instream flow determinations. U.S. Forest Service Region 4 Report. 32 pp.

Thompson, K. E. 1972. Determining stream-flows for fish life. In Proc. Instream Flow Requirement Workshop, Pacific N.W. River Basins Comm., Portland, Oregon. pp. 31-50.

Thompson, K. E. 1974. Salmonids--Chap. 7. In Bayha, K. (ed.), The Anatomy of a River. Report of the Hells Canyon Task Force, Pacific N.W. River Basins Comm. pp. 85-103.

Trautman, M. B. 1933. The general effects of pollution on Ohio fish life. Trans. Amer. Fish. Soc. 63:69-72.

U.S. Department of the Interior. 1973. Water Resources Data for Wyoming. Part 1. Surface Water Records. U.S. Geological Survey Report. 244 pp.

U.S. Department of the Interior. 1977. Cooperative instream flow service group, the first year. FWS/OBS-77/36. 8 pp.

U.S. Department of the Interior. 1979. Instream flow guidelines. Bureau of Land Management Report. 57 pp.

Vaux, W. G. 1962. Interchange of stream and intergravel water in a salmon spawning riffle. USFWS Spec. Sci. Rept. Fish. 405. 11 pp.

Warner, K., and I. Porter. 1960. Experimental improvement of a bull-dozed trout stream in northern Maine. Trans. Amer. Fish. Soc. 89(1):59-63.

Waters, T. F. 1969. Invertebrate drift-ecology and significance to stream fishes. In Symposium on Salmon and Trout in Streams, H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B. C. pp. 121-134.

Waters, Brian F. 1976a. A methodology for evaluating the effects of different stream-flows on salmonid habitat. In Proc. Symp. and Spec. Conf. on Instream Flow Needs, ed. J. F. Orsborn and C. H. Allman. Vol. II, pp. 254-266. Amer. Fish. Soc., Bethesda, Md.

Waters, Brian F. 1976b. Outline: Investigational techniques for relating changes in streamflow to changes in fish habitat. Pacific Gas and Electric Co., San Ramon, California. 3 pp.

Webster, D. A., and G. Eiriksdotter. 1976. Upwelling water as a factor influencing choice of spawning sites by brook trout (Salvelinus fontinalis). Trans. Amer. Fish. Soc. 105(3):416-421.

Welch, P. W. 1963. Limnology. 2nd Ed. McGraw-Hill Book Company, New York. 538 pp.

Wesche, T. A. 1973. Parametric determination of minimum stream flow for trout. Water Resources Series No. 37. Water Resources Research Institute, Univ. of Wyoming, Laramie, Wyoming. 102 pp.

Wesche, T. A. 1974. Relationship of discharge reductions to available trout habitat for recommending suitable streamflows. Water Resources Series No. 53. Water Resources Research Institute, Univ. of Wyoming, Laramie, Wyoming. 71 pp.

Wesche, T. A., D. W. Reiser, W. F. Wichers, and D. L. Wichers. 1977. Fishery resources and instream flow recommendations for streams to be impacted by Cheyenne's proposed Phase II development. Water Resources Research Institute Report to Wyoming Game and Fish Department. Laramie, Wyo. 62 pp.

White, H. C. 1930. Some observations on eastern brook trout (S. fontinalis) of Prince Edward Island. Trans. Amer. Fish. Soc. 60:101-108.

White, Robert, and Tim Cochnauer. 1975. Stream resource maintenance flow studies. Idaho Dept. of Fish and Game and Idaho Coop. Fishery Research Unit Report. 136 pp.

White, Robert G. 1976. A methodology for recommending stream resource maintenance flows for large rivers. In Proceedings of the Symp. and Spec. Conf. on Instream Flow needs, ed. J. F. Orsborn and C. H. Allman. Vol. II, pp. 367-386. Amer. Fish. Soc., Bethesda, Md.

Wichers, D. L. and T. A. Wesche. 1980 (in press). Telemetric determination of salmonid winter microhabitat occupation and movement in ice-covered streams. Water Resources Research Institute Publ., Univ. of Wyoming, Laramie.

Wickett, Percy W. 1954. The oxygen supply to salmon eggs in spawning beds. Jour. Fish. Res. Bd. Canada 11(6):933-953.

Wickham, G. M. 1967. Physical microhabitat of trout. Master's Thesis, Colorado State Univ., Ft. Collins. 42 pp.

APPENDIX A:

LIFE HISTORY INFORMATION AND HABITAT CRITERIA FOR VARIOUS FISH SPECIES

GENERAL DEPTH, VELOCITY, AND SUBSTRATE HABITAT CRITERIA

| Species | Source | Depth meter | Depth feet | Velocity cm/sec | Velocity ft/sec | Substrate inch (cm) | Fish Size inch (mm) | Remarks |
|---|---|---|---|---|---|---|---|---|
| Chinook Salmon (O. tschawytcha) | Everest and Chapman, 1972 | 0.15-0.30 | 0.49-0.98 | <15 | <0.49 | -- | 2.4 (62) | From Giger, 1973 |
| Chinook Salmon | Thompson, 1972 | 0.30-1.22 | 0.98-4.00 | 6-24 | 0.20-0.79 | -- | -- | From Giger, 1973 |
| Coho Salmon (O. kisutch) | Pearson et al 1970 | -- | -- | 9-21 | 0.29-0.69 | -- | 2.6-3.5 (66-89) | From Giger, 1973 |
| Coho Salmon | Thompson, 1972 | 0.30-1.22 | 0.98-4.00 | 6-24 | 0.20-0.79 | -- | -- | From Giger, 1973 |
| Steelhead Trout (S. gairdneri) | Everest and Chapman, 1972 | <0.15 | <0.49 | <15 | <0.49 | -- | 1.3 (32) | From Giger, 1973 |
| Steelhead Trout | Everest and Chapman, 1972 | 0.60-0.75 | 1.97-2.46 | 15-30 | 0.49-0.98 | -- | 3.7 (95) | From Giger, 1973 |
| Steelhead Trout | Thompson, 1972 | 0.18-0.67 | 0.59-2.20 | 6-49 | 0.20-1.61 | -- | Varied | From Giger, 1973 |
| Rainbow Trout (S. gairdneri) | Bovee, 1975 | 0.31-1.2 | 1.02-3.94 | 5-40 | 0.16-1.31 | 0.20-1.96 (0.5-5) | -- | ----- |
| Rainbow Trout | Waters, 1975 | >0.09 | >0.30 | 0.0-30.5 | 0.00-1.00 | silt-rubble | | Criteria are assigned weighting factors designating the relative worth of a given interval. The intervals given here represent the total range of depths, velocities and substrates assigned weighting factors. For specific intervals and weighting factors see Table |
| Brook Trout (S. fontinalis) | Wickham, 1967 | -- | -- | 10 (ave) | 0.33 (ave) | -- | 7.9 (200) | From Giger, 1973 |
| Brook Trout | Bovee, 1975 | -- | -- | 5-40 | 0.16-1.31 | 0.20-1.96 (0.5-5) | -- | ----- |
| Brown Trout (S. trutta) | Baldes and Vincent, 1969 | -- | -- | 12-21 | 0.39-0.69 | -- | 8.4 (213) | From Giger, 1973 |
| Brown Trout | Hunter, 1973 | -- | -- | 12-21 | 0.40-0.70 | -- | -- | ----- |
| Brown Trout | Wesche, 1973 | >0.15 | >0.50 | -- | -- | >3.0 (>7.6) | -- | ----- |
| Brown Trout | Bovee, 1975 | 0.31-1.2 | 1.02-3.94 | 5-40 | 0.16-1.31 | 0.20-1.96 (0.5-5) | -- | ----- |
| Cutthroat Trout (S. clarki) | Thompson, 1972 | 0.40-1.22 | 1.31-4.00 | 6-49 | 0.20-1.61 | -- | Varied | From Giger, 1973 |
| Trout | Banks et al, 1974 | >0.46 | >1.5 | 0-30 | 0.0-0.99 | -- | -- | ----- |
| Trout | Hooper, 1973 | -- | -- | 9-31 | 0.30-1.00 | -- | -- | ----- |
| Yellow Perch (P. flavescens) | Bovee, 1975 | 1.8-2.5 | 5.90-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Sauger (S. canadense) | Bovee, 1975 | 2.1-2.5 | 6.89-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Walleye (S. vitreum vitreum) | Bovee, 1975 | 2.1-2.5 | 6.89-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Northern Pike (E. lucius) | Bovee, 1975 | 0.61-2.5 | 2.00-8.20 | 0-0.05 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Black Bullhead (I. melas) | Bovee, 1975 | 0.31-2.5 | 1.02-8.20 | 0-0.05 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Yellow Bullhead (I. natalis) | Bovee, 1975 | 0.31-2.5 | 1.02-8.20 | 0-0.05 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Stonecat (N. flavus) | Bovee, 1975 | 0.15-0.31 | 0.49-1.02 | 150 | 4.92 | 11.8 (30) | -- | ----- |
| Channel Catfish (I. punctatus) | Bovee, 1975 | 0.31-1.5 | 1.02-4.92 | 5-40 | 0.16-1.31 | 0.20-1.96 (0.5-5) | -- | ----- |
| Smallmouth Bass (M. dolomieui) | Bovee, 1975 | 0.31-1.2 | 1.02-3.94 | 5-40 | 0.16-1.31 | 0.20-1.96 (0.5-5) | -- | ----- |
| Largemouth Bass (M. salmoides) | Bovee, 1975 | 0.91-2.5 | 2.98-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |

HABITAT CRITERIA (CONTINUED)

| Species | Source | Depth meter | Depth feet | Velocity cm/sec | Velocity ft/sec | Substrate inch (cm) | Fish Size inch (mm) | Remarks |
|---|---|---|---|---|---|---|---|---|
| Rock Bass (A. rupestris) | Bovee, 1975 | 0.61-1.2 | 2.00-3.94 | 5-40 | 0.16-1.31 | 0.20-1.96 (0.5-5) | -- | ----- |
| Bluegill (L. macrochirus) | Bovee, 1975 | 0.91-2.5 | 2.98-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| White Crappie (P. annularis) | Bovee, 1975 | 0.91-2.5 | 2.98-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Black Crappie (P. nigromaculatus) | Bovee, 1975 | 0.91-2.5 | 2.98-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Green Sunfish (L. cyanellus) | Bovee, 1975 | 0.91-2.5 | 2.98-8.20 | -- | -- | -- | -- | ----- |
| Pumpkin Seed (L. gibbossus) | Bovee, 1975 | 0.91-2.5 | 2.98-8.20 | -- | -- | -- | -- | ----- |
| River Carpsucker (C. carpio) | Bovee, 1975 | 0.91-2.5 | 2.98-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Smallmouth Buffalo (I. bubalus) | Bovee, 1975 | 0.91-2.5 | 2.98-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Bigmouth Buffalo (I. cyprinellus) | Bovee, 1975 | 1.8-2.5 | 5.90-8.20 | -- | -- | | -- | ----- |
| Longnose Sucker (C. catostomus) | Bovee, 1975 | 0.15-2.5 | 0.49-8.20 | 0.5-150 | 0.016-4.92 | 0.02-11.80 (0.05-30) | -- | ----- |
| White Sucker (C. commersoni) | Bovee, 1975 | 0.15-2.5 | 0.49-8.20 | 0.5-150 | 0.016-4.92 | 0.02-11.80 (0.05-30) | -- | ----- |
| Blue Sucker (C. elongatus) | Bovee, 1975 | -- | -- | 5-150 | 0.16-4.92 | 0.20-11.80 (0.5-30) | -- | ----- |
| Shorthead Redhorse (M. macrolepidotum) | Bovee, 1975 | 0.15-0.61 | 0.49-2.00 | 5-150 | 0.16-4.92 | 0.20-11.80 (0.5-30) | -- | ----- |
| Carp (C. carpio) | Bovee, 1975 | 0.91-2.5 | 2.98-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Sturgeon Chub (H. gelida) | Bovee, 1975 | -- | -- | 40-150 | 1.31-4.92 | 1.96-11.80 (5-30) | -- | ----- |
| Creek Chub (S. atromaculatus) | Bovee, 1975 | 0.15-0.61 | 0.49-2.00 | 5-40 | 0.16-1.31 | 0.20-1.96 (0.5-5) | -- | ----- |
| Pearl Dace (S. margarita) | Bovee, 1975 | 0.15-0.61 | 0.49-2.00 | 5-40 | 0.16-1.31 | 0.20-1.96 (0.5-5) | -- | ----- |
| Emerald Shiner (N. atherinoides) | Bovee, 1975 | 0.15-0.91 | 0.49-2.98 | 5-40 | 0.16-1.31 | 0.20-1.96 (0.5-5) | -- | ----- |
| Sand Shiner (N. stramineus missuriensis) | Bovee, 1975 | 0.15-0.31 | 0.49-1.02 | 5-40 | 0.16-1.31 | 0.20-1.96 (0.5-5) | -- | ----- |
| Plains Minnow (H. placitus) | Bovee, 1975 | 0.61-1.5 | 2.00-4.92 | 0.5-40 | 0.016-1.31 | 0.02-1.96 (0.05-5) | -- | ----- |
| Brassy Minnow (H. hankinsoni) | Bovee, 1975 | 0.91-1.5 | 0.49-4.92 | 0.5-40 | 0.016-1.31 | 0.02-1.96 (0.05-5) | -- | ----- |
| Silvery Minnow (H. nuchalis) | Bovee, 1975 | 0.61-1.5 | 2.00-4.92 | 0.5-40 | 0.016-1.31 | 0.02-1.96 (0.05-5) | -- | ----- |
| Golden Shiner (N. crysoleucas) | Bovee, 1975 | 0.61-2.5 | 2.00-8.20 | 0-0.5 | 0.00-0.016 | 0.02 (0.05) | -- | ----- |
| Fathead Minnow (P. promelas) | Bovee, 1975 | 0.15-1.5 | 0.49-4.92 | -- | -- | -- | -- | ----- |
| Flathead Chub (H. gracilis) | Bovee, 1975 | 0.15-2.5 | 0.49-8.20 | 0.5-150 | 0.016-4.92 | 0.02-11.8 (0.05-30) | -- | ----- |
| Longnose Dace (R. cataractae) | Bovee, 1975 | 0.15-0.31 | 0.49-1.02 | 40-150 | 1.31-4.92 | 1.96-11.8 (5-30) | -- | ----- |
| Shovelnose Sturgeon (S. platorynchus) | Bovee, 1975 | -- | -- | 40-150 | 1.31-4.92 | 1.96-11.8 (5-30) | -- | ----- |
| Burbot (L. lota) | Bovee, 1975 | 0.15-0.61 | 0.49-2.00 | 40-150 | 1.31-4.92 | 1.96-11.8 (5-30) | -- | ----- |

GAME FISH LIFE HISTORY

| Species Common Name (Scientific Name) | Source | Distribution | Water: Warm | Water: Cool | Water: Cold | Habitat | Spawning Time | Spawning Temperature °C (°F) | Fecundity (# of Eggs) | Egg Incubation Time | Age at Maturation (years) | Size Range kg (lb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chinook Salmon (Fall) (Onchyrynchus tschawytscha) | Bell, 1973; Scott & Crossman, 1973 | Coastal rivers & streams | | | X | Small-large coastal streams and rivers | Sep-Jan | 5.5-13.8 (42-57) | 5000-6000 | Sep-Mar | 3-5 | 4.5-22.7 (10-50) |
| Chinook Salmon (Spring) (Onchyrynchus tschawytscha) | Bell, 1973; Scott & Crossman, 1973 | Coastal rivers & streams | | | X | Small-large coastal streams and rivers | Jul-Oct | 5.5-13.8 (42-57) | 5000 Ave | Oct-Jan | 4-6 | 4.5-9.1 (10-20) |
| Chinook Salmon (Summer) (Onchyrynchus tschawytscha) | Bell, 1973; Scott & Crossman, 1973 | Columbia River & upper tributaries | | | X | Small-large coastal streams and rivers | Sep-Nov | 5.5-13.8 (42-57) | 5000 Ave | Oct-Feb Estimation | 4-6 | 4.5-13.6 (10-30) |
| Chum Salmon (Dog) (Onchyrynchus keta) | Bell, 1973; Scott & Crossman, 1973 | Coastal rivers & streams | | | X | Small-large coastal streams and rivers | Sep-Jan | 7.2-12.7 (45-55) | 3000 Ave | Sep-Mar | 3-4 | 3.6-5.4 (8-12) |
| Coho Salmon (Silver) (Onchyrynchus kisutch) | Bell, 1973; Baxter & Simon, 1970; Scott & Crossman, 1973 | Coastal rivers & streams; introduced into Great Lakes & several western states | | | X | Small-large coastal streams & rivers | Oct-Jan | 10.0-12.7 (50-55) | 3000-4000 | Oct-May | 3-4 | 2.3-9.1 (5-20) |
| Pink Salmon (Humpback) (Onchyrynchus gorbuscha) | Bell, 1973; Scott & Crossman, 1973 | Coastal rivers & streams; British Columbia & south-eastern Alaska | | | X | Small-large coastal streams and rivers | Aug-Oct | 7.2-12.7 (45-55) | 1500-2700 | Aug-Feb | 2 | 1.4-4.5 (3-10) |
| Sockeye Salmon (Blueback) (Onchyrynchus nerka) | Bell, 1973 | Columbia River to Alaska | | | X | Large streams that provide lake habitat | Aug-Nov | 10.0-12.7 (50-55) | 3500 Ave | Nov-Feb | 3-5 | 1.4-3.6 (3-8) |
| Kokanee (Onchyrynchus nerka) | Bell, 1973; Baxter & Simon, 1970; Minckley, 1973 | California, Oregon, Washington, & British Columbia in large, cool lakes & reservoirs; recently introduced in other western states | | | X | Large, cool lakes & reservoirs | Aug-Jan | 5.0-12.7 (41-55) | 400-500 Fish -- 11"-12" | Aug-Feb | 2-7 | 0.06-0.45 (1/8-1) |
| Steelhead (Summer) (Salmo gairdneri) | Bell, 1973 | Coastal rivers & streams; Washington, Columbia River | | | X | Coastal streams & river systems | Feb-Jun | 3.8-12.7 (39-55) | 5000 Ave | Feb-Jul | 3-6 | 2.3-13.6 (5-30) |
| Steelhead (Winter) (Salmo gairdneri) | Bell, 1973 | Washington streams; Columbia River | | | X | Coastal streams & river systems | Feb-Jun | 3.8-12.7 (39-55) | 3500 Ave | Feb-Jul | 3-6 | 2.3-12.7 (5-28) |
| Steelhead (Fall) (Salmo gairdneri) | Bell, 1973 | Sacramento River | | | X | Coastal streams & river systems | Jan-Mar | 3.8-19.4 (39-58) | 1500 Ave | Jan-Apr | 2-3 | 0.45-5.4 (1-12) |
| Steelhead (Spring) (Salmo gairdneri) | Bell, 1973 | Columbia River | | | X | Coastal streams & river systems | Dec-Mar | 3.8-12.7 (39-55) | 2500 Ave | Dec-May | 3-5 | 2.3-9.1 (5-20) |
| Rainbow Trout (Salmo gairdneri) | Bell, 1973 | Throughout U.S. in cold streams and lakes | | | X | Streams & lakes of varying size | Spring Feb-Jun | -- | 1500 Ave | Feb-Aug | 3-4 | 0.11-19.1 (1/4-42) |
| Arizona Trout (Salmo apache) | Minckley, 1973 | Native to White Mountains in east central Arizona; introduced into other isolated regions in Arizona | | | | Small, clear, cold mountain brooks; beaver ponds | Mar-Apr | | 200-600 | Apr-May | 2-3 | 15-18 cm (6-15 in) |

GAME FISH LIFE HISTORY

| Species Common Name (Scientific Name) | Source | Distribution | Water: Warm | Water: Cool | Water: Cold | Habitat | Spawning Time | Spawning Temperature °C (°F) | Fecundity (# of Eggs) | Egg Incubation Time | Age at Maturation (years) | Size Range kg (lb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brook Trout (Char) (_Salvelinus fontinalis_) | Bell, 1973; Baxter & Simon, 1970, Minckley, 1973 | Introduced throughout U.S. in cold streams & lakes; native to eastern U.S. | | | X | Small, high-altitude lakes, streams & beaver ponds; also, plains lakes | Aug-Dec | 2.7-13.8 (37-57) | 500-1500 | Sep-Feb | 1-2 | 0.06-2.3 (1/8-5) |
| Brown Trout (_Salmo trutta_) | Baxter & Simon, 1970; Bell, 1973 | Native trout of Europe; introduced throughout U.S. in cold streams & lakes | | | X | Streams of mountains, foothills, & plains; lakes & reservoirs | Sep-Jan | 2.7-15.5 (37-60) | 1000-1500 | Oct-Mar | 3-4 | 0.11-18.1 (1/4-40) |
| Colorado River Cutthroat (_Salmo clarki pleuritieus_) | Baxter & Simon, 1970; Hunter, 1973; Bell, 1973 | Originally in cold water tributaries of the Green River; today, Wyoming; headwater streams of Little Snake drainage; Colorado, streams & tributaries of Trappers Lake | | | X | Small, cold, clean & well-oxygenated mountain streams | Mar-Jul | 6.1-17.2 (43-63) | | Mar-Aug | 3-4 | |
| Cutthroat Trout (_Salmo clarki_--subspecies) Greenback Trout (_Salmo clarki stomias_) | Baxter & Simon, 1970; Gagnon, 1974 | Native to a few small streams in the South Platte drainage in Colo.; Como Creek; Black Hollow | | | X | Small, cold, clean, & well-oxygenated mountain streams | Spring | | | | | ≤25 cm (≤10 in) |
| Lahontan Cutthroat (_Salmo clarki henshawi_) | Baxter & Simon, 1970; Bell, 1973 | Native to Lahontan Basin in Nevada & California; established in Wyoming in Eight Mile Lake & Chapman & Teton reservoirs in Carbon County; Arizona--Lake Mead | | | X | Large lakes, streams, & rivers; alkaline lakes of the desert | Mar-Jul | 6.1-17.2 (43-63) | | Mar-Aug | 3-4 | 0.11-18.6 (1/4-41) |
| Utah Cutthroat (_Salmo clarki utah_) | Sigler & Miller, 1963 | Originally in Bonneville Basin of Utah, Idaho, & Wyoming; today thought to be extinct | | | | --- | -- | -- | -- | -- | -- | -- |
| Yellowstone Cutthroat (_Salmo clarki lewisi_) | Baxter & Simon, 1970; Sigler & Miller, 1963; Belle, 1973; Hunter, 1973 | Native to headwaters of Missouri River, Columbia River, upper Fraser River in British Columbia, & S. Sasketchewan River in Alberta; planted in many drainages of western North America | | | X | Mountain lakes & streams | Mar-Jul | 6.1-17.2 (43-63) | 1000 Ave | Mar-Aug | 3-4 | 0.11-18.6 (1/4-41) |
| Dolly Varden (Char) (_Salvelinus malma_) | Bell, 1973; Hunter, 1973 | Native to Pacific slope from McCloud River, California to Kamchatka and west to Japan | | | X | Deep water lakes; gravelly rivers & streams | Aug-Nov | 10.0-12.7 (50-55) | 1500-3500 | Aug-Jan | 4-6 | 0.11-9.1 (1/4-20) |
| Gila Trout (_Salmo gilae_) | Minckley, 1973 | Originally in tributaries of the Verde River (Arizona) & Gila River (New Mexico); today at least 3-4 high eleva-elevation creeks in New Mexico; programs to restock certain Arizona waters are underway | | | X | High elevation creeks | | | 150-200 | | [illegible]-3 | 18-30 cm (7-12 in) |

| Species Common Name (Scientific Name) | Source | Distribution | Water: Warm | Water: Cool | Water: Cold | Habitat | Spawning Time | Spawning Temperature °C (°F) | Fecundity (# of Eggs) | Egg Incubation Time | Age at Maturation (years) | Size Range kg (lb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Golden Trout (Salmo aguabonita) | Curtis, 1934; Hunter, 1973 | Native to south fork of Kern River (California); introduced throughout western U.S. in high, cold, mountain lakes | | | X | Alpine lakes & streams | Jun-Aug (ice-out) | 6.6-12.7 (44-55) | 300-2000 | Jun-Oct | 3-4 | 0.11-4.9 (1/4-11) |
| Lake Trout (Char) (Salvelinus namaycush) | Bell, 1973; Sigler & Miller, 1963 Baxter & Simon, 1970 | Native to Canada & the Great Lakes from the Yukon to the Atlantic coast; introduced into many large, deep, coldwater lakes in the west | | | X | Large deep lakes | Aug-Dec | 7.2-10.0 (45-50) | 2000-6000 | Sep-Mar | 4-5 | 0.45-36.2 (1-80) |
| Mexican Golden Trout (Salmo chrysogaster) | Needham & Gard, 1964 | Fuerte, Sinaloa, & Culiacan river systems in western Chihuahua & northwest Durango | | | X | Rivers & streams | | | | | | 5-13 cm (2-5 in) |
| Grayling (Thymallus arcticus) | Hunter, 1973; Rayner, 1974; McClane, 1974; Sigler & Miller, 1963 | Native to northern Canada extending south to Michigan, Montana, & Wyoming; introduced into numerous lakes throughout the west | | | X | Streams, small lakes, and bays of large lakes | Mar-Jun | 4.4-11.1 (40-52) | 1000-13,000 | Mar-Aug | 3 | 0.11-2.7 (1/4-6) |
| Mountain Whitefish (Prosopium williamsoni) | Baxter & Simon, 1970; Sigler & Miller, 1963; Bell, 1973 | Occurs in waters of the Columbia, Lahonton, Bonneville, Colorado, & upper Missouri drainages | | | X | Mountain lakes & streams | Oct-Dec | 1.6-9.4 (35-49) | 1400-24,000 | Oct-Feb | 2-4 | 0.06-1.8 (1/8-4) |
| Burbot (Ling) (Lota lota) | Baxter & Simon, 1970 | Occurs throughout Canada from Arctic Circle south to Missouri & Kansas & east to New England; native to Bighorn & Tongue Rivers in Wyoming; large population in Ocean Lake, Wyoming | | X | | Deep lakes & large rivers | Dec-Feb | | 1,000,000 Ave | | | 0.23-10.8 (1/2-24) |
| Northern Pike (Esox lucius) | Baxter & Simon, 1970; Scott & Crossman, 1973 | Common from New York through the Great Lakes regions to Nebraska; introduced into many waters of the south and west; recently into Keyhole Reservoir in Wyoming | | X | | Clear, slow, meandering, heavily vegetated rivers or weedy bays of lakes | Apr-Jul (ice out) | 4.4-11.1 (40-52) | 32,000 Ave | 12-14 days from spawning | 2-3 | 0.45-18.1 (1-40) |
| Walleye (Stizostedion vitreum vitreum) | Baxter & Simon, 1970; Scott & Crossman, 1973; Sigler & Miller, 1963 | Native to southern Canada & the Dakotas east to the Atlantic coast & south to southern Alabama & Georgia; introduced into many western waters | | X | | Lakes, reservoirs, & clear rivers | Apr-Jun | 5.5-11.1 (42-52) | 100,000-600,000 | 12-18 days from spawning | 2-3 | 0.45-10.4 (1-23) |
| Sauger (Stizostedion canadense) | Baxter & Simon, 1970; Scott & Crossman, 1973 | Occurs from southern Canada east to New England south to Arkansas & Tennessee & west to Montana & Wyoming | | X | | Large rivers & streams, reservoirs | May-Jun | 3.8-6.1 (39-43) | 9000-96,000 | 25-29 days from spawning | 2-4 | 0.11-3.6 (1/4-8) |
| Yellow Perch (Perca flavescens) | Baxter & Simon, 1970; Scott & Crossman, 1973 | Native to southern Canada & eastern South Dakota east to Pennsylvania & south to Missouri; introduced into many western waters | | X | | Lakes, reservoirs, & sluggish streams | Apr-Jun | 6.6-12.2 (44-54) | 4000-40,000 | 8-27 days from spawning | 3-4 | 0.06-1.4 (1/8-3) |

GAME FISH LIFE HISTORY

| Species Common Name (Scientific Name) | Source | Distribution | Water: Warm | Water: Cool | Water: Cold | Habitat | Spawning Time | Spawning Temperature °C (°F) | Fecundity (# of Eggs) | Egg Incubation Time | Age at Maturation (years) | Size Range kg (lb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Smallmouth Bass (Micropterus dolomieui) | Baxter & Simon, 1970; Scott & Crossman, 1973 Bell, 1973 | Native to eastern South Dakota across the Great Lake states to the St. Lawrence system, south to northern Georgia, Alabama, & to the Ozarks farther west; introduced into many western waters | X | | | Streams, lakes & reservoirs | Mar-Jul | 12.8-20.0 (55-68) | 5000-14,000 | 4-10 days from spawning | 2-3 | 0.27-2.3 (1/2-5) |
| Largemouth Bass (Micropterus salmoides) | Baxter & Simon, 1970; Bell, 1973; Scott & Crossman, 1973; Sigler & Miller, 1963 | From southern Canada & through the Great Lakes States to Florida & northeastern Mexico; introduced into many western waters | X | | | Lakes & reservoirs; streams with weeded coves | Apr-Jun | 16.7-18.3 (62-65) | 2000-25,000 | 3-5 days from spawning | 1-2 | 0.27-4.5 (1/2-10) |
| Spotted Bass (Micropterus punctulatus) | Minckley, 1973 | Indigenous to the Ohio & lower Mississippi River basins & to some coastal drainages of Texas, east to Alabama; introduced into a few western waters--Arizona--in the Verde River System | X | | | Rivers & streams with deep well/shaded pools; reservoirs & lakes | Mar-May | 15.0-18.0 (59-64) | | 4-5 days from spawning | 2-3 | ≤2.3 (≤5) |
| Green Sunfish (Lepomis cyanellus) | Baxter & Simon, 1970; Bell, 1973; Scott & Crossman, 1973 | From the Great Lakes to the Rio Grande River along the Mexican border & from the Alleghanies to Nebraska, Colorado, & New Mexico; introduced into other western lakes & streams | X | | | Lakes, reservoirs, & sluggish streams | May-Jul | 20.0-27.7 (68-82) | 1500 | 3-5 days after spawning | 1-2 | 0.06-0.27 (1/8-1/2) |
| Pumpkin Seed (Lepomis gibbosus) | Baxter & Simon, 1970 | From North Dakota to Quebec, south to the Carolinas & the upper Mississippi Valley | X | | | Ponds, lakes, reservoirs, & sluggish streams with abundant aquatic vegetation | Apr-Sep | 20.0-27.7 (68-82) | 1500 | 3 days after spawning | | 0.06-0.27 (1/8-1/2) |
| Bluegill (Lepomis macrochirus) | Baxter & Simon, 1970; Scott & Crossman, 1973; Bell, 1973 | From South Dakota to Lake Champlain & south to Florida & Texas | X | | | Ponds, lakes, reservoirs, & sluggish streams | Apr-Sep | 20.0-24.4 (68-76) | 3000 | 3-5 days from spawning | 1-2 | 0.06-0.23 (1/8-1/2) |
| Rock Bass (Ambloplites rupestris) | Baxter & Simon, 1970; Scott & Crossman, 1973; Minckley, 1973 | From Manitoba east through the Great Lakes states to New York & south to Oklahoma; introduced into many western waters | X | | | Streams, lakes, & reservoirs | May-Jun | 15.5-21.1 (60-70) | 3000-11,000 | 3-4 days from spawning | | 0.06-0.23 (1/8-1/2) |
| Redear Sunfish (Lepomis microlophus) | K. Buss in McClane, 1974; Baxter & Simon, 1970 | From soutern Illinois south to Florida & Texas; introduced into western waters | X | | | Lakes, reservoirs, farm ponds | Apr-Jun | 20.0-27.7 (68-82) | | 3 days after spawning | | ≤1.8 (≤4) |
| Sacramento Perch (Archoplites interruptus) | Minckley, 1973; Bell, 1973; K. Buss in McClane, 1974; Sigler & Miller, 1963 | Native to the Sacramento San Joaquin drainage & the Pajaro River system in California; introduced into a few western waters--Nevada, Utah, Arizona | X | | | Sluggish river channels & clear lakes | May-Aug | 21.1-26.6 (70-80) | 84,000 | | 1-2 | 0.11-1.4 (1/4-3) |

| Species Common Name (Scientific Name) | Source | Distribution | Water: Warm | Water: Cool | Water: Cold | Habitat | Spawning Time | Spawning Temperature °C (°F) | Fecundity (# of Eggs) | Egg Incubation Time | Age at Maturation (years) | Size Range kg (lb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| White Crappie (Pomoxis annularis) | Baxter & Simon, 1970; Bell, 1973; Minckley, 1973; Scott & Crossman, 1973 | From eastern South Dakota & the southern Great Lakes region south to Texas; introduced into many western waters | X | | | Lakes, reservoirs, & river sloughs | Mar-Jul | 13.8-22.7 (57-73) | 2000-14,000 | 2-4 days after spawning | 2-3 | 0.15-1.8 (1/3-4) |
| Black Crappie (Pomoxis nigromaculatus) | Baxter & Simon, 1970; Bell, 1973; Scott & Crossman, 1973, Sigler & Miller, 1963 | From Manitoba south to Texas & east to the Atlantic coast; introduced into many western waters | X | | | Lakes, reservoirs, & river sloughs | Mar-Jul | 14.4-17.7 (58-64) | 20,000-60,000 | 3-5 days after spawning | 2-3 | 0.15-1.8 (1/3-4) |
| Carp (Cyprinus carpio) | Baxter & Simon, 1970; Minckley, 1973; Scott & Crossman, 1973 Sigler & Miller, 1963; Bell, 1973 | Native to Asia; introduced to the U.S. & now widely distributed throughout North America | X | | | Lakes, reservoirs, ponds, & sluggish streams with abundant aquatic vegetation | Mar-Aug | 15.5-20.0 (60-68) | 500,000-1,000,000 | 3-6 days after spawning | 1-3 | 0.11-27.2 (1/4-60) |
| Channel Catfish (Ictalurus punctatus) | Baxter & Simon, 1970; Sigler & Miller, 1963; Bell, 1973 | From the prane provinces of Canada & Montana east through the Great Lakes states & south to Florida & northern Mexico; widely introduced throughout North America | X | | | Lakes, reservoirs, & streams in areas of moderate current | May-Jul | 21.1-29.4 (70-85) | 4000-40,000 | 5-10 days after spawning | 5-8 | 0.11-5.9 (1/4-13) |
| Black Bullhead (Ictalurus melas) | Baxter & Simon, 1970; Sigler & Miller, 1963; Scott & Crossman, 1973; Bell, 1973 | From New York west to the Rocky Mountains & from Manitoba south to Tennessee; widely introduced throughout southern & western U.S. | X | | | Ponds, lakes, reservoirs, & sluggish streams | Apr-Jun | 18.3-21.1 (65-70) | 2000-12,000 | 5-15 days after spawning | 3 | 0.11-1.4 (1/4-3) |
| Yellow Bullhead (Ictalurus natalis) | Bell, 1973; Scott & Crossman, 1973; R. Jones in McClane, 1974; Minckley, 1973 | From North Dakota to the Hudson River & south to Florida; introduced into western waters | X | | | Clear lakes, reservoirs, & rocky bottomed streams | Apr-Jun | ≥20.5 (≥69) | 2000-12,000 | 5-10 days after spawning | 3 | 0.11-1.4 (1/4-3) |
| Brown Bullhead (Ictalurus nebulosus) | Bell, 1973; Scott & Crossman, 1973; R. Jones in McClane, 1974 | From Maine & the Great Lakes south to Florida & Mexico; introduced into western waters | X | | | Ponds, lakes, reservoirs, & sluggish streams | Apr-Jun | ≥20.5 (≥69) | 2000-12,000 | | 3 | 0.11-1.4 (1/4-3) |
| Flathead Catfish (Pilodictis olivaris) | Minckley, 1973; R. Jones in McClane, 1974; Deacon, 1961 | From the Mississippi River basin, southeast & southwest in coastal drainages to the Rio Grande system & into Mexico; introduced into the Gila River system & the Colorado River | X | | | Large rivers with long, deep sluggish pools | Spring & early summer Apr-Jun | | | 8-9 days from spawning | | 1.4-45.4 (3-100) |
| White Sturgeon (Acipenser transmontanus) | Minckley, 1973; Scott & Crossman, 1973; Bell, 1973 | Pacific shores of North America from the Aleutian Islands of Alaska to Monterey, California; introduced into a few western waters--Lake Havasu, Colorado River in Arizona | | X | | Ocean; migrates up large rivers to spawn; some are landlocked in large rivers or lakes | Mar-Jul | 8.8-16.6 (48-62) | 50,000-5,000,000 | 1-2 weeks after spawning | 9-20 | 2.3-816.5 (5-1800) |

GAME FISH LIFE HISTORY

| Species Common Name (Scientific Name) | Source | Distribution | Water Warm | Water Cool | Water Cold | Habitat | Spawning Time | Spawning Temperature °C (°F) | Fecundity (# of Eggs) | Egg Incubation Time | Age at Maturation (years) | Size Range kg (lb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bigmouth Buffalo (Ictiobus cyprinellus) | J. Shields in McClane, 1974; Minckley, 1973; Scott & Crossman, 1973; Clay, 1975 | From North Dakota & southern Saskatchewan east to Ohio & Pennsylvania & south to the Gulf; introduced into western waters | X | | | Large rivers & shallow lakes, reservoirs | Apr-Jun | 15.5-18.3 (60-65) | ≤500,000 | 2 weeks after spawning | 3 | 0.91-9.1 (2-20) |
| Black Buffalo (Ictiobus niger) | Clay, 1975; Minckley, 1973 | Large streams in the Mississippi basin from the Gulf coast north to Nebraska, Wisconsin & Pennsylvania; introduced into western waters | X | | | Large streams & lakes | Spring-Summer | | | | | 0.91-5.9 (2-13) |
| Smallmouth Buffalo (Ictiobus bubalus) | Clay, 1975; J. Shields in McClane, 1974 | From northeastern Mexico & the lower Mississippi valley north to Minnesota & southern Canada & throughout the Ohio River basin to Pennsylvania; introduced into western waters | X | | | Large rivers & warm lakes | Apr-Jun | 15.5-18.3 (60-65) | | | 3 | 0.91-7.7 (2-17) |
| Paddlefish (Polydon spathula) | Clay, 1975; C. Purkett in McClane, 1974 | Mississippi River system including the Missouri River into Montana, the Ohio River & major tributaries | X | | | Large rivers, lakes, & reservoirs | Apr-May | 15.0-16.1 (59-61) | 80,000-250,000 | 5-10 days after spawning | | 6.8-40.8 (15-90) |

DEPTH, VELOCITY, AND SUBSTRATE SPAWNING CRITERIA

| Species | Source | Depth meter (feet) | Velocity cm/sec (ft/sec) | Substrate cm (inch) | Fish Size cm (inch) | How and Where Developed | Remarks |
|---|---|---|---|---|---|---|---|
| Chinook Salmon (O. tschawytcha) | Hamilton & Remington, 1962 | >0.24 (>0.80) | >31 (>1.00) | -- | -- | Oregon--Coquille River | --- |
| Fall Chinook | Warner, 1953 Westgate, 1958 | 0.12-1.22 (0.40-4.00) | 15-107 (0.50-3.50) | -- | -- | California--American & Cosumnes Rivers | --- |
| Fall Chinook | Keir, 1964 Rantz, 1964 | >0.24 (>0.80) | 31-92 (1.00-3.00) | -- | -- | California--Feather, Eel & Mad River Systems | --- |
| Fall Chinook | Horton & Rogers, 1969 | >0.21 (>0.70) | 37-107 (1.20-3.50) | -- | -- | California--Van Duzen River | --- |
| Fall Chinook | Chambers et al, 1955 | 0.30-0.46 (1.00-1.50) | 30-69 (1.00-2.25) | -- | -- | Washington--Columbia River & tributaries | $\overline{V}$ at 0.4' above bed |
| Fall Chinook | Sams & Pearson, 1963 | 0.09-0.46 (0.30-1.50) | 30-94 (0.90-3.10) | -- | -- | Oregon--4 streams in Willamette River Basin | $\overline{V}$ at 0.6' depth or 0.2' and 0.8' depth from surface |
| Fall Chinook | Thompson, 1972 | >0.24 (>0.80) | 30-91 (1.00-3.00) | -- | -- | 90-95% confidence interval; Oregon--on a wide range of streams | 440 redds sampled; streams represented a wide variation of hydraulic characteristics |
| Fall Chinook | Smith, 1973 | >0.24 (>0.80) | 30-76 (1.00-2.50) | -- | -- | Tolerance interval; Oregon--7 streams with varying hydraulic conditions | 50 redds sampled; $\overline{V}$ at 0.4' above bed |
| Spring Chinook | Chambers et al, 1955 | 0.46-0.53 (1.50-1.75) | 53-69 (1.75-2.27) | -- | -- | Washington--Columbia River & tributaries | $\overline{V}$ at 0.4' above bed |
| Spring Chinook | Sams & Pearson, 1963 | 0.09-0.61 (0.30-2.00) | <13-85 (<0.43-2.8) | -- | -- | Oregon--4 streams in Willamette River Basin | $\overline{V}$ at 0.6' depth or 0.2' and 0.8' depth from surface |
| Spring Chinook | Thompson, 1972 | >0.24 (>0.80) | 30-91 (1.00-3.00) | -- | -- | 90-95% confidence interval; Oregon--on a wide range of streams | 158 redds sampled; streams represented a wide variation of hydraulic characteristics |
| Spring Chinook | Smith, 1973 | >0.18 (>0.60) | 21-64 (0.70-2.10) | -- | -- | Tolerance interval; Oregon--7 streams with varying hydraulic conditions | 142 redds sampled; $\overline{V}$ at 0.4' above bed |
| Chum Salmon (O. keta) | Collings, 1974 | 0.15-0.53 (0.50-1.75) | 21-101 (0.70-3.30) | -- | -- | --- | $\overline{V}$ measured 0.4' above bed |
| Chum | Smith, 1973 | >0.18 (>0.60) | 46-101 (1.50-3.30 | -- | -- | Tolerance interval; Oregon--5 streams with varying hydraulic conditions | 214 redds sampled; $\overline{V}$ at 0.4' above bed |
| Chum | Thompson, 1972 | >0.18 (>0.60) | 46-97 (1.50-3.20) | -- | -- | 90-95% confidence interval; Oregon--on a wide range of streams | 177 redds sampled; streams represented a wide variation of hydraulic characteristics |
| Coho Salmon (O. kisutch) | Chambers et al, 1955 | 0.30-0.38 (1.00-1.25) | 37-55 (1.20-1.80) | -- | -- | Washington--Columbia River & tributaries | Redds measured 0.4' above stream bed |
| Coho | Sams & Pearson, 1963 | 0.09-0.57 (0.30-1.90) | 15-91 (0.50-3.00) | -- | -- | Oregon--4 streams on Willamette River Basin | $\overline{V}$ measured at 0.6' depth or 0.2' and 0.8' depth from surface |
| Coho | Thompson, 1972 | >0.18 (>0.60) | 30-91 (1.00-3.00) | -- | -- | 90-95% confidence interval; Oregon--10-12 streams with varying hydraulic conditions | 251 redds sampled; streams represented a wide variation of hydraulic characteristics |
| Coho | Smith, 1973 | >0.15 (>0.50) | 21-70 (0.70-2.30) | -- | -- | Tolerance interval; Oregon--7 streams with varying hydraulic conditions | 128 redds sampled; $\overline{V}$ measured 0.4' above bed |
| Pink Salmon (O. gorbuscha) | Collings, 1974 | 0.15-0.53 (0.50-1.75) | 21-101 (0.70-3.30) | -- | -- | --- | $\overline{V}$ measured 0.4' above bed |
| Sockeye Salmon (O. nerka) | Chambers et al, 1955 | 0.30-0.46 (1.00-1.50) | 53 (1.75) | -- | -- | Washington | $\overline{V}$ at 0.4' above bed |
| Sockeye | Clay, 1961 | -- | 53-55 (1.75-1.80) | -- | -- | --- | $\overline{V}$ at 0.4' above bed |
| Kokanee (O. nerka) | Thompson, 1972 | 0.12-0.18 (0.40-0.60) | 24-64 (0.80-2.10) | -- | 30-46 (12-18) | 90-95% confidence interval val; Oregon--on a wide range of streams | 106 redds sampled; streams represented a wide variation of hydraulic characteristics |

SPAWNING CRITERIA (CONTINUED)

| Species | Source | Depth meter (feet) | Velocity cm/sec (ft/sec) | Substrate cm (inch) | Fish Size cm (inch) | How and Where Developed | Remarks |
|---|---|---|---|---|---|---|---|
| Kokanee | Smith, 1973 | ≥0.06 (≥0.20) | 15-73 (0.50-2.40) | -- | -- | Tolerance interval; Oregon--3 streams with varying hydraulic conditions | 106 redds sampled; $\overline{V}$ at 0.4' above bed |
| Kokanee | Hunter, 1973 | 0.09-0.36 (0.30-1.10) | 12-41 (0.40-1.36) | -- | 25-43 (10-17) | Middle 80% measurements; Washington--Q's from 2-30 cfs | 177 redds sampled; $\overline{V}$ at 0.4' or 0.25-0.30' above bed* |
| Steelhead (S. gairdnerii) | Oregon | 0.35-0.43 (1.14-1.40) | 60-69 (1.96-2.28) | -- | -- | 95% confidence interval; Oregon | 51 redds sampled |
| Steelhead (winter) | Smith, 1973 | ≥0.24 (≥0.80 | 40-91 (1.30-3.00) | -- | -- | Tolerance interval; Oregon--11 streams with varying hydraulic conditions | 115 redds sampled; $\overline{V}$ at 0.4' above bed |
| Steelhead (winter) | Engman, 1970 | 0.10->0.9 (0.33->3.0) | 23-117 (0.75-3.84) | -- | -- | Range; Washington | 62 redds sampled |
| Steelhead (winter) | Hunter, 1973 | 0.21-0.70 (0.70-2.30) | 37-101 (1.20-3.30) | 0.64-10.16 (0.25-4.0) | -- | Middle 90% of measurements; Washington--19 streams with varying hydraulic conditions | 114 redds sampled; $\overline{V}$ at 0.4' or 0.25-0.30' above bed |
| Steelhead (winter) | Hunter, 1973 | 0.12-0.36 (0.40-1.20) | 44-109 (1.45-3.57) | 0.64-12.70 (0.25-5.0) | -- | Range; Washington | 19 redds sampled; $\overline{V}$ at 0.4' or 0.25-0.30' above bed* |
| Steelhead (winter) | Hunter, 1976 | 0.23-0.50 (0.75-1.65) | 41-89 (1.33-2.91) | -- | -- | Range; Washington--on streams of 180 cfs | 20 redds sampled; $\overline{V}$ at 0.4' or 0.25-0.30' above bed |
| Steelhead (winter) | Hunter, 1976 | 0.26-0.44 (0.85-1.45) | 65-108 (2.14-3.55) | -- | -- | Range; Washington--on streams of 180 cfs | 10 redds sampled; $\overline{V}$ at 0.4' or 0.25-0.30' above bed |
| Steelhead (winter) | Hunter, 1976 | 0.14-0.20 (0.45-0.65) | 25-34 (0.82-1.11) | -- | -- | Range; Washington--Satsop River; Q = 15 cfs | 4 redds sampled; $\overline{V}$ at 0.4' or 0.25-0.30' above bed |
| Steelhead (summer) | Smith, 1973 | ≥0.24 (≥0.80) | 43-97 (1.42-3.18) | -- | -- | Tolerance interval; Oregon--Deschutes River | 90 redds sampled $\overline{V}$; 83 redds sampled D; $\overline{V}$ at 0.4' above bed |
| Steelhead (summer) | Smith, 1973 | >0.15 (>0.50) | 45-91 (1.48-3.00) | -- | -- | Tolerance interval; Oregon--Rogue River System | 46 redds sampled; $\overline{V}$ at 0.4' above bed |
| Steelhead (summer) | Orcutt, Pulliam & Arp, 1968 | 0.21->1.52 (0.70->5.0) | 24-155 (0.80-5.10) | 1.27-10.16 (0.5-4.0) | -- | Range; Idaho--6 streams in Clearwater & Salmon River watersheds | 54 redds sampled; V measured at the surface |
| Arizona Trout (S. apache) | --- | ≥0.06 (≥0.20) | 4-34 (0.12-1.11) | 0.33-5.08 (0.13-2.0) | ≤25 (≤10) | Estimate | These criterion are the same as for brook trout as determined by Reiser & Wesche (1976); their applicability to the Arizona trout is based on their inhabiting streams of similar size with similar flow regimes. |
| Brook Trout (S. fontinalis) | Smith, 1973 | ≥0.09 (≥0.30) | 0.9-23 (0.03-0.75) | -- | -- | Tolerance interval; Oregon--4 streams with varying hydraulic conditions | 122 redds sampled; $\overline{V}$ at 0.4' from bed |
| Brook Trout | Hooper, 1973 | -- | 6-91 (0.20-3.00) | coarse sand-gravel 7.62 (3.0) | -- | Range; California | --- |
| Brook Trout | Bovee, 1974 | 0.15 (0.50) | 15-91 (0.50-3.00) | gravel | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Brook Trout | Oregon Game Co. | ≥0.24 (≥0.80) | 21-64 (0.70-2.10) | -- | 20-30 (8-12) | 90-95% confidence interval; Oregon--on a wide range of streams | 115 redds sampled; streams represented a wide variation of hydraulic characteristics |
| Brook Trout | Hunter, 1973 | 0.12-0.61 (0.40-2.00) | 10-41 (0.33-1.36) | 0.64-7.62 (0.25-3.0) | 20-25 (8-10) | Middle 80%; Washington--on streams of 1-10 cfs | 120 redds sampled; $\overline{V}$ at 0.4' or 0.25-0.30' from bed |
| Brook Trout | Reiser & Wesche, 1976 | ≥0.06 (≥0.20) | 4-34 (0.12-1.11) | 0.33-5.08 (0.13-2.0) | ≤25 (≤10) | Middle 80%; Wyoming--small streams in southeastern Wyoming; Q's from 4.1-9.0 cfs | 54 redds sampled; Q's during spawning measurements; Telephone Creek (4.1 cfs); Douglas Creek (9.0 cfs); $\overline{V}$ at 0.6' from surface |
| Brown Trout (S. trutta) | Smith, 1973 | ≥0.24 (≥0.80) | 20-68 (0.67-2.24) | 0.64-7.62 (0.25-3.0) (Hunter, 1973) | -- | Tolerance interval; Oregon--5 streams with varying hydraulic conditions | 115 redds sampled; $\overline{V}$ at 0.4' from bed |

SPAWNING CRITERIA (CONTINUED)

| Species | Source | Depth meter (feet) | Velocity cm/sec (ft/sec) | Substrate cm (inch) | Fish Size cm (inch) | How and Where Developed | Remarks |
|---|---|---|---|---|---|---|---|
| Brown Trout | Hoppe & Finnell, 1972 | -- | ≥46 (≥1.50) | -- | -- | Based on velocity versus egg mortality; Colorado--Fryingpan River | Relates more to egg incubation than spawning; $\bar{V}$ at 0.6' from surface |
| Brown Trout | Thompson, 1972 | >0.24 (>0.80) | 21-64 (0.70-2.10) | -- | -- | 90-95% confidence interval; Oregon--on a wide range of streams | 115 redds sampled; streams represented a wide variation of hydraulic characteristics |
| Brown Trout | Hooper, 1973 | -- | 30-91 (1.00-3.00) | 0.64-7.62 (0.25-3.0) | -- | Range; California | --- |
| Brown Trout | Bovee, 1974 | ≥0.15 (≥0.50) | 40-52 (1.31-1.70) | gravel | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Brown Trout | Reiser & Wesche, 1976 | ≥0.09 (≥0.30) | 14-46 (0.45-1.50) | 0.64-7.62 (0.25-3.0) | ≤41 (≤16) | Middle 80%; Wyoming--small streams in southeastern Wyoming; Q's from 0.9-48.9 cfs | 121 redds sampled; Q's during spawning measurements; Douglas Creek (9 cfs); Hog Park (5.5-0.9 cfs); Lake Creek (1.5 cfs); Laramie River (48.9 cfs); $\bar{V}$ at 0.6' from surface |
| Cutthroat Trout (S. clarki) | Hooper, 1973 | -- | 30-91 (1.00-3.00) | 0.64-10.16 (0.25-4.0) | -- | Range; California | --- |
| Cutthroat Trout | Cedarhome, 1972 | 0.08-0.15 (0.25-0.50) | 8-26 (0.25-0.85) | -- | -- | Range; Washington | 3 redds sampled; insufficient data base for accurate criterion |
| Cutthroat Trout (resident) | Hunter, 1973 | 0.06-0.27 (0.20-0.90) | 11-38 (0.35-1.25) | 0.64-5.08 (0.25-2.0) | 18-30 (7-12) | Range; Washington--on streams of 0.5-2 cfs | 23 redds sampled; 13 on streams with 0.5 cfs; $\bar{V}$ at 0.4' or 0.25-0.30' from bed |
| Cutthroat Trout (sea-run) | Hunter, 1973 | 0.12-0.40 (0.40-1.30) | 15-56 (0.50-1.83) | 0.64-10.16 (0.25-4.0) | 41-46 (16-18) | Range; Washington--on streams of 5-15 cfs | 16 redds sampled; 12 on 5 cfs streams; 1 on 10-15 cfs stream; $\bar{V}$ at 0.4' or 0.25-0.30' from bed |
| Cutthroat Trout (mixed) | Hunter, 1973 | 0.06-0.46 (0.20-1.50) | 11-72 (0.35-2.37) | -- | -- | Range; Washington | 53 redds sampled; $\bar{V}$ at 0.4' or 0.25-0.30' from bed |
| Dolly Varden (S. malma) | Hunter, 1973 | 0.21-0.43 (0.70-1.40) | 34-65 (1.13-2.15) | 0-15.24 (0.0-6.0) | 4-5 kg (8-10 lb) | Range; Washington--Skokonish River; Q > 100 cfs | 6 redds sampled |
| Gila Trout (S. gilae) | | ≥0.06 (≥0.20) | 4-34 (0.12-1.11) | 0.13-2.0 (0.33-5.08) | ≤25 (≤10) | Estimate | These criterion are the same as for brook trout as determined by Reiser & Wesche (1976); their applicability to the gila trout is based on their inhabiting streams of similar size with similar flow regimes |
| Golden Trout (S. aguabonita) | Hunter, 1976 | Similar to resident Cutthroat Trout of same size (Hunter, 1973) | | | | Estimate | Inferred from literature |
| Rainbow Trout (S. gairdnerii) | Smith, 1973 | ≥0.18 (≥0.60) | 48-91 (1.60-2.98) | 0.64-5.18 (0.25-2.0) | -- | Tolerance interval; Oregon--Deschutes River | 51 redds sampled; $\bar{V}$ at 0.4' above bed |
| Rainbow Trout | Calif. in Hooper, 1973 | 0.21-0.33 (0.70-1.10) | 43-82 (1.40-2.70) | 1.27-3.81 (0.5-1.5) | 30-36 (12-14) | Range; California--south fork of Feather River; Q = 90 cfs | 10 redds sampled; $\bar{V}$ at 0.2' above bed |
| Rainbow Trout | Bovee, 1974 | 0.15 (0.50) | 43-82 (1.42-2.69) | gravel | -- | Estimated from literature review | --- |
| Rainbow Trout | Waters, 1975 | 0.09-0.90 (0.29-3.00) | 21-91 (0.69-3.00) | -- | -- | California--Pit River | Criteria are assigned weighting factors designating the relative worth of a given interval. The intervals given here represent the total range of depths and velocities assigned weighting factors. For specific intervals and weighting factors, see Table |
| Grayling (T. articus) | Hunter, 1973 | ≥0.12 (≥0.40) | -- | 0-15.24 (0.0-6.0) | -- | Estimated from literature review | --- |
| Whitefish (P. williamsoni) | Hunter, 1973 | ≥0.12 (≥0.40) | -- | 0-15.24 (0.0-6.0) | -- | Estimated from literature review | --- |

SPAWNING CRITERIA (CONTINUED)

| Species | Source | Depth meter (feet) | Velocity cm/sec (ft/sec) | Substrate cm (inch) | Fish Size cm (inch) | How and Where Developed | Remarks |
|---|---|---|---|---|---|---|---|
| Smallmouth Bass (M. dolomieui) | Bovee, 1974 | 0.90-1.80 (2.95-5.90) | 11 (0.36) | sand-rubble | -- | Estimated from literature review; Northern Great Plains | V estimated from substrate type; little field verification of criterion |
| Smallmouth Bass | Scott & Crossman, 1973 | 0.60-6.10 (1.97-20.01) | -- | -- | -- | -- | --- |
| Largemouth Bass (M. salmoides) | Bovee, 1974 | 0.30-1.80 (0.98-5.90) | Still | root-debris gravel (Clay, 1975) | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Bluegill (L. macrochirus) | Bovee, 1974 | 0.30-1.20 (0.98-3.94) | Still | sand | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| White Crappie (P. annularis) | Bovee, 1974 | 0.60-2.50 (1.97-8.20) | Still | -- | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Black Crappie (P. nigromaculatus) | Bovee, 1974 | 0.20-6.00 (0.66-19.7) | Still | -- | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Black Bullhead (I. melas) | Bovee, 1974 | 0.60-1.20 (1.97-3.94) | Still | mud-sand | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Yellow Bullhead (I. natalis) | Bovee, 1974 | 0.30-1.20 (0.98-3.94) | Still | mud-sand | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Northern Pike (E. lucius) | Bovee, 1974 | -- | Still | marsh-grass | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Yellow Perch (P. flavescens) | Bovee, 1974 | 1.50-3.10 (4.92-10.2) | Still | -- | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Walleye (S. vitreum vitreum) | Bovee, 1974 | 1.20-1.50 (3.94-4.92) | 0-50 (0.00-1.64) | gravel | -- | Estimated from literature review; Northern Great Plains | V estimated from substrate type; little field verification of criterion |
| Sauger (S. canadense) | Bovee, 1974 | 1.20-1.50 (3.94-4.92) | 0-50 (0.00-1.64) | gravel | -- | Estimated from literature review; Northern Great Plains | V estimated from substrate type; little field verification of criterion |
| Shovelnose Sturgeon (S. platorynchus) | Bovee, 1974 | 0.30-0.90 (0.98-2.95) | 75-150 (2.46-4.92) | rubble | -- | Estimated from literature review; Northern Great Plains | V estimated from substrate type; little field verification of criterion |
| Shovelnose Sturgeon | Bovee, 1976 | 0.60-1.00 (1.97-3.28) | 70-110 (2.30-3.61) | sand-gravel | -- | Chi square 2 x 2 matrix; no significant difference at 80% level; Montana | Tagged 78 sturgeon and noted where spawned; 58 of 78 sturgeon fell within criterion; sand substrate used always in dune form; V at 0.6' from surface |
| Lake Sturgeon (A. fulvescens) | Carlander, 1969 | 0.60-4.60 (1.97-15.09) | -- | sand-gravel (Clay, 1975) | -- | --- | --- |
| Lake Sturgeon | Scott & Crossman, 1973 | 0.60-4.60 (1.97-15.09) | -- | -- | -- | --- | --- |
| Sturgeon Russian sp. | White, 1975 | 1.50-5.00 (5.00-16.4) | 70-110 (2.30-3.61) | -- | -- | --- | --- |
| Longnose Sucker (C. catostomus) | Bovee, 1974 | 0.20-0.30 (0.66-0.98) | 31-45 (1.02-1.48) | gravel | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| White Sucker (C. commersoni) | Bovee, 1974 | 0.20-0.30 (0.66-0.98 | 31-45 (1.02-1.48) | gravel | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |

SPAWNING CRITERIA (CONTINUED)

| Species | Source | Depth meter (feet) | Velocity cm/sec (ft/sec) | Substrate cm (inch) | Fish Size cm (inch) | How and Where Developed | Remarks |
|---|---|---|---|---|---|---|---|
| Shorthead Redhorse (M. macrolepidotum) | Bovee, 1974 | 0.30-0.09 (0.9B-2.95) | 31-61 (1.02-2.00) | gravel | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| River Carpsucker (C. carpio) | Bovee, 1974 | 0.15 (0.49) | Still | debris | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Smallmouth Buffalo (I. bubalus) | Bovee, 1974 | 0.15 (0.49) | Still | mud-vegetation (Clay, 1975) | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Carp (C. carpio) | Bovee, 1974 | 0.15 (0.49) | Still | detritus | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Creek Chub (S. atromaculatus) | Bovee, 1974 | -- | 49-91 (1.61-2.98) | gravel | -- | Estimated from literature review; Northern Great Plains | V estimated from substrate type; little field verification of criterion |
| Golden Shiner (N. crysoleucas) | Bovee, 1974 | -- | Still | vegetation | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Sand Shiner (N. stramineus missuriensis) | Bovee, 1974 | -- | -- | sand | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Fathead Minnow (P. promelas) | Bovee, 1974 | 0.03-0.60 (0.09-1.97) | Still | -- | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Longnose Dace (R. cataractae) | Bovee, 1974 | 0.03-0.30 (0.09-0.98) | 15-45 (0.49-1.48) | gravel | -- | Estimated from literature review; Northern Great Plains | Little field verification of criterion |
| Paddlefish (P. spathula) | Bovee, 1974 | -- | 49-91 (1.61-2.98) | gravel | -- | Estimated from literature review; Northern Great Plains | V estimated from bottom type; little field verification of criterion |

FISH PASSAGE CRITERIA

| Species | Source | Minimum Depth | | Average Depth | | Maximum Velocity | | Average Velocity | | Where Developed | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Meter | Feet | Meter | Feet | cm/sec | ft/sec | cm/sec | ft/sec | | |
| Chinook Salmon (*O. tschawytcha*) | Thompson 1972 | 0.24 | 0.8 | -- | -- | 243.8 | 8.0 | -- | -- | Oregon | |
| Coho Salmon (*O. kisutch*) | Thompson 1972 | 0.18 | 0.6 | -- | -- | 243.8 | 8.0 | -- | -- | Oregon | |
| Chum Salmon (*O. keta*) | Thompson 1972 | 0.18 | 0.6 | -- | -- | 243.8 | 8.0 | -- | -- | Oregon | |
| Steelhead Trout (*S. gairdneri*) | Thompson 1972 | 0.18 | 0.6 | -- | -- | 243.8 | 8.0 | -- | -- | Oregon | |
| Large Trout ≥ 20" | Thompson 1972 | 0.18 | 0.6 | -- | -- | 243.8 | 8.0 | -- | -- | Oregon | |
| Other Trout < 20" | Thompson 1972 | 0.12 | 0.4 | -- | -- | 121.9 | 4.0 | -- | -- | Oregon | |
| Colorado Trout (on streams 20 ft or greater) | Colo. Div. of Wild. 1976 | -- | -- | 0.15-0.18 across riffles | 0.5-0.6 across riffles | -- | -- | 30.5-45.7 | 1.0-1.5 | Colorado | Only on coldwater streams |
| Colorado Trout (on streams 10-20 ft wide) | Colo. Div. of Wild. 1976 | -- | -- | 0.6-0.12 across riffles | 0.2-0.4 across riffles | -- | -- | 30.5-45.7 | 1.0-1.5 | Colorado | Only on coldwater streams |
| White Sturgeon (*A. transmontanus*) | White 1975 | 1.52 | 5.0 | -- | -- | -- | -- | -- | -- | Idaho--Middle Snake River | Preliminary Recommendation |

AQUATIC INVERTEBRATE (GENERAL)
DEPTH, VELOCITY AND SUBSTRATE PRODUCTION CRITERIA

| Source | Depth meter | Depth feet | Velocity cm/sec | Velocity ft/sec | Substrate Inch (cm) | Where Developed | Remarks |
|---|---|---|---|---|---|---|---|
| Surber, 1951 | -- | -- | 15.2-106.7 | 0.5-3.5 | -- | Virginia--St. Mary's River | Velocity measured at surface. |
| Needham and Usinger, 1956 | -- | -- | 61.0-106.7 | 2.0-3.5 | -- | California--Prosser Creek near Truckee | Test conducted on fast, shallow and uniform riffle. |
| Radway, 1952 | >0.15 | >0.49 | >30.2 | >0.99 | -- | New Zealand | |
| Delisle and Eliason, 1961 | -- | -- | 15.2-91.4 | 0.5-3.0 | >2.0-rubble (>5.1) | California--Middle Fork Feather River | Velocity near the bottom. |
| Kennedy, 1967 | 0.08-0.15 | 0.25-0.5 | 15.2-91.4 | 0.5-3.0 | 2.6-7.0 (6.6-17.8) | --- | --- |
| Pearson et al 1970 | -- | -- | 15.2-121.9 | 0.5-4.0 | -- | Oregon | --- |
| Thompson, 1972 | -- | -- | 30.5-45.7 | 1.0-1.5 | -- | Oregon | --- |
| Giger, 1973 | -- | -- | 30.5-61.0 | 1.0-2.0 | -- | Oregon | --- |
| Hooper, 1973 | -- | -- | 45.7-106.7 | 1.5-3.5 | -- | California | --- |
| Banks et al, 1974 | 0.15-0.91 | 0.5-2.99 | 45.7-106.4 | 1.5-3.49 | -- | Wyoming--Green River | --- |
| Kimble and Wesche, 1975 | <0.30 | <1.00 | >15.2 | >0.50 | 0-9.8 (0-25) sand-rubble | Wyoming--Hog Park Creek | Velocity measured with Steven's midget meter. Average daily flow of Hog Park = 27 cfs. Sampled July-August. |
| Waters, 1975 | 0.06-1.52 | 0.20-5.00 | 15.2-131.1 | 0.50-4.30 | 0.125-12.0 (0.3-30.5) | California--Pit River (for Rainbow Trout) | Criteria are assigned weighting factors designating the relative worth of a given interval. The intervals given here represent the total range of depths, velocities and substrates assigned weighting factors. For specific intervals and weighting factors see |

AQUATIC INVERTEBRATE (SPECIFIC)
DEPTH, VELOCITY AND SUBSTRATE PRODUCTION CRITERIA

| Group/ (Organism) | Source | Depth meter | Depth feet | Velocity cm/sec | Velocity ft/sec | Substrate inch (cm) | How Developed | Where Developed | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Diptera Flies | Radway, 1952 | <0.38 | <1.25 | <30.5 | <1.00 | -- | -- | New Zealand | --- |
| Diptera (Simulium) | Arthur, 1963 | -- | -- | 58.2-112.5 | 1.91-3.69 | -- | Mean ± 1 Standard Deviation | California--Kern River above Fairview Dam | Velocity measured with pygmy current meter 3.0 cm from substrate; samples taken--September |
| Ephemeroptera mayflies | Radway, 1952 | >0.15 | >0.49 | >30.2 | >0.99 | -- | -- | New Zealand | --- |
| Ephemeroptera | Needham and Usinger, 1956 | <0.30 | <1.00 | 36.6-79.2 | 1.2-2.6 | -- | -- | California--Prosser Creek near Truckee | Test conducted on fast, shallow and uniform riffle |
| Ephemeroptera (Rithrogena) | Arthur, 1963 | -- | -- | 37.5-102.7 | 1.23-3.37 | -- | Mean ± 1 Standard Deviation | California--Kern River above Fairview Dam | Velocity measured with pygmy current meter 3.0 cm from substrate; samples taken--September |
| Ephemeroptera (Baetis) | Arthur, 1963 | -- | -- | 31.1-92.0 | 1.02-3.02 | -- | Mean ± 1 Standard Deviation | California--Kern River above Fairview Dam | Velocity measured with pygmy current meter 3.0 cm from substrate; samples taken--September |
| Ephemeroptera (Ephemerella) | Arthur, 1963 | -- | -- | 31.4-86.3 | 1.03-2.83 | -- | Mean ± 1 Standard Deviation | California--Kern River above Fairview Dam | Velocity measured with pygmy current meter 3.0 cm from substrate; samples taken--September |
| Ephemeroptera | Kimble and Wesche, 1975 | <0.30 | <1.00 | >15.2 | >0.50 | 0.0-9.8 (0.0-25) sand-rubble | Frequency Distribution | Wyoming--Hog Park Creek | Velocity measured with Steven's midget meter at substrate surface; average daily flow of Hog Park = 27 cfs; sampled--July-August |
| Trichoptera caddisfly | Radway, 1952 | >0.15 | >0.49 | >30.2 | >0.99 | -- | -- | New Zealand | --- |
| Trichoptera | Needham and Usinger, 1956 | 0.30 | 1.00 | 91.4 | 3.0 | -- | -- | California--Prosser Creek near Truckee | Test conducted on fast, shallow and uniform riffle |
| Trichoptera (Hydropsyche) | Arthur, 1963 | -- | -- | 31.4-111.9 | 1.03-3.67 | -- | Mean ± 1 Standard Deviation | California--Kern River above Fairview Dam | Velocity measured with pygmy current meter 3.0 cm from substrate; samples taken--September |
| Trichoptera | Kimble and Wesche, 1975 | <0.30 | <1.00 | >15.2 | >0.50 | 2.5-9.8 (6.41-25) rubble | Frequency Distribution | Wyoming--Hog Park Creek | Velocity measured with Steven's midget meter at substrate surface; average daily flow of Hog Park = 27 cfs; sampled--July-August |
| Plecoptera stoneflies | Radway, 1952 | >0.15 | >0.49 | >30.2 | >0.99 | -- | -- | New Zealand | --- |
| Plecoptera (arcynopteryx) | Arthur, 1963 | -- | -- | 27.1-69.2 | 0.89-2.27 | -- | Mean ± 1 Standard Deviation | California--Kern River above Fairview Dam | Velocity measured with pygmy current meter 3.0 cm from substrate; samples taken--September |
| Plecoptera | Kimble and Wesche, 1975 | <0.30 | <1.00 | >15.2 | >0.50 | 0.0-9.8 (0.0-25) sand-rubble | Frequency Distribution | Wyoming--Hog Park Creek | Velocity measured with Steven's midget meter at substrate surface; average daily flow of Hog Park = 27 cfs; sampled--July-August |

## APPENDIX B

## LITERATURE SUMMARY

The four fundamental components of salmonid habitat are water quality, food-producing areas, spawning-egg incubation areas, and cover. The extent to which each of these components is present in a given stream is dependent upon the stream's physical, chemical and hydraulic characteristics and the flow at any given time. To provide a suitable habitat for a salmonid population, no matter how large or small the stream, a proper range of flows is required through the channel configuration which the stream itself has formed. For example, a flow of one cubic foot per second (cfs) may provide an excellent habitat in a very small stream, but it would barely wet the gravels in a large river such as the Green or the Snake river in western Wyoming. To further complicate matters, flows which satisfy one of the components do not necessarily satisfy the other three, and the question arises as to which of the components is the most important. The answer to the question is an unequivocal, "they all are," with each habitat constituent directly influencing the type and quality of salmonid fishery that is able to exist under a given set of conditions. At certain times, one of the elements may indeed seem more important than the others, for example the presence of spawning-incubation areas during the spawning season. However, an abundance of spawning area will be of little value to the fishery if the water is polluted, if there is no food, and if protective cover is absent. A careful look at each of the components will lead to a better understanding of its importance in comprising salmonid habitat.

### Water Quality

Four of the primary water quality parameters for salmonid habitat are water temperature, dissolved oxygen, pH, and total suspended solids (TSS). In order for each to be considered "acceptable" for salmonids, they must fall within a certain range.

#### Temperature

Because trout have difficulty extracting oxygen from water with temperatures much over 70°F (21°C) regardless of the amount of oxygen present, Hooper (1973) states that a good trout stream should have summer temperatures in the range of 50-60°F (10-15°C) with an upper limit of 68°F (20°C). Mills (1971) defines the optimum temperatures for salmonid growth between 44-62°F (7-17°C), with the upper lethal limits below 82°F (28°C). According to Tebo (1974) temperature affects all metabolic and reproductive activities of fish including such critical functions as growth, swimming, and the ability to capture and assimilate food. Accordingly, optimum temperature requirements may vary, depending on season and life stage. The optimum temperature range for trout during spawning is 37-55°F (3-13°C) while for egg incubation a range of 42-54°F (6-12°C) is optimum (Hooper, 1973). With salmonids it is the upper temperature limits within the ranges that are the most critical and limiting, with the lower limits resulting in slower growth rates and slower egg development.

#### Dissolved Oxygen

Water temperature affects the quantity of oxygen which can be absorbed, with cold water having a greater capacity to hold dissolved oxygen than warm water (Welch, 1963). As water temperatures increase, there is a corresponding increase in the metabolic rate of salmonids resulting in increased oxygen requirements. However, as noted earlier, trout cannot extract oxygen efficiently from waters with elevated temperatures. In general, salmonid waters should have a dissolved oxygen concentration of at least 80 percent of saturation for a given temperature, which should never be reduced to below 5 mg/l (Mills, 1971; Hooper, 1973).

#### pH

The hydrogen ion concentration (acid or alkaline intensity) of a stream is usually expressed in values of pH, with values between 0 and 7 being acidic and values between 7 and 14 being alkaline. Ellis, Westfall, and Ellis (1946) found that in 90 percent of the areas supporting good freshwater fish faunas, the pH ranged from 6.7 to 8.2. Welch (1963) lists the expected pH range for lakes and streams as 6.5-8.5. According to Leitritz (1969) and Mills (1971), the best water for fish possesses a slightly alkaline reaction, that is, a pH between 7 and 8.

#### Total Suspended Solids (TSS)

Turbidity is a condition of water resulting from the presence of suspended solids (Welch, 1963). The amount of suspended solids which can be transported by a stream is dependent upon the stream velocity and particle size. Thus, unless influenced by continuous point

discharges of sediments or by suspensoids of colloidal dimensions, most trout streams are quite clear during periods of low or normal streamflow (Tebo, 1974). However, certain conditions both man-made and/or natural may increase the stream load of suspended solids, adversely affecting the salmonid habitat.

Numerous investigators (Bachmann, 1958; Campbell, 1954; Pautzke, 1938; Ellis, 1944; Kemp, 1949; Trautman, 1933; Gammon, 1970; Cordone and Kelley, 1961; Bell, 1973; and others) have shown that increased turbidities have the potential to detrimentally affect fish by direct clogging or cutting of their gill filaments. However, the general consensus is that the direct effects of turbidity on the adult fish are insignificant when compared to the indirect effects on the stream quality and productivity, and that adult fish are able to withstand normal high concentrations of TSS without harm (Tebo, 1974; Cordone and Kelley, 1961). Because salmonids are sight feeders, increased turbidity in a stream reduces the effectiveness of trout feeding ability. Working with cutthroat trout (Salmo clarki), Bachmann (1958) found that fish ceased to feed in turbidities of 35 ppm. Spawning migrations may also be adversely affected by increased TSS, as studies in the Chilcotin River in British Columbia indicate that salmonids will not move in streams where the silt content is above 4,000 ppm (Bell, 1973). Other individuals (Cordone and Kelley, 1961; Bartsch, 1960; Tarzwell, 1957; Chapman, 1962; and others) have noted that increased turbidity decreased light penetration, resulting in a reduction in a productivity of instream plants. In general, streams with silt loads averaging between 80 and 400 ppm should not be considered good areas for supporting freshwater fisheries; streams with less than 25 ppm may be expected to support good freshwater fisheries (Bell, 1973).

The importance of the above-mentioned water quality parameters is exemplified by the fact that salmonid waters have received special consideration from regulatory agencies involved in water pollution control through the establishment of stringent water quality standards. The following table lists the water quality standards for salmonid waters in three southeastern and three western states (from Tebo, 1974).

TABLE B-1. Water quality standards for salmonid waters.

| State | Dissolved Oxygen (mg/l) | Temperature | Turbidity |
|---|---|---|---|
| North Carolina | 6.0 | 68°F (20°C) max; No increase over ambient permitted. | No limit specified. |
| Georgia | 5.0 | No change permitted. | No limit specified. |
| Tennessee | 6.0 | 68°F (20°C) max; 5.4°F (3°C) over ambient. | None harmful to fish life. |
| Colorado | 6.0 | 68°F (20°C) max; 2°F (1.1°C) over background. | 10 JTU over background. |
| Montana | 7.0 | 68°F (20°C) max; 2°F (1.1°C) over background. | 5 JTU over background. |
| Wyoming | 6.0 | 68°F (20°C) max; 2°F (1.1°C) over background; no increase over spawning areas. | 10 JTU over background. |

## Food-Producing Areas

There are generally two types of habitat exhibited in streams; riffles and pools (Odum, 1959). Riffles are characterized by having a greater than average velocity, a less than average depth and substrates composed of gravel-rubble; pools are characterized by having a less than average velocity, a greater than average depth and substrates composed of silt-fine gravel. Of the two, riffles are the primary food-producing areas. Careful examination of the parameters, velocity, depth and substrate size will explain the reasons for this.

### Velocity

According to Scott (1958) and Allen (1959), velocity is the most important parameter in determining distributional patterns of aquatic invertebrates. These invertebrates (benthos) live in a vertically constricted boundary layer (Pradtl's layer) between the water mass and the stream substrate (Giger, 1973). At this level, water velocities would be at or near zero since velocity varies approximately as a parabola from zero at the bottom to a maximum at or near the surface (Linsley, Kohler, and Paulhus, 1975). Ambuhl

(1959) states that current velocity becomes important to the benthic invertebrate by governing the rate of oxygen renewal to the boundary layer. Logically, the faster the water current, the faster and more efficient the renewal rate. In fact, Eriksen (1966) felt that water velocity was perhaps of greater significance to respiration than the actual dissolved oxygen content of the water. Ambuhl (1959) showed the importance of velocity by showing that some species of invertebrate die quickly in oxygen-rich still water while living in oxygen-poor running water. Apparently, many of the swift-water invertebrates lack the morphological features and mechanisms which are present on many still-water forms for creating their own currents for respiration. Organisms in rapids communities do exhibit adaptation for maintaining position in swift water. Odum (1959) lists some of the more important adaptations: (1) permanent attachment to the substrate; (2) hooks and suckers; (3) sticky undersurfaces; (4) streamlined bodies (5) flattened bodies; (6) positive rheotaxis (orient upstream); and (7) positive thigmotaxis.

According to Ruttner (1953), the influence of water current is manifested in the quantity of organisms produced per unit area. Increased water velocities increase the exchange rate between the organism and its water supply, thereby promoting respiration and food acquisition (Giger, 1973). Eriksen (1966) felt the importance of water current lies in its ability to renew the respiratory environment of forms that do not have the capability to do so for themselves.

Studies have been conducted which relate water velocity to numbers of organisms. Kennedy (1967) found the greatest numbers of organisms associated with velocities of 1.0-1.2 fps, with few invertebrates present in lower velocities. Needham and Usinger (1956) found the highest numbers of Ephemeroptera (mayflies) associated with velocities of 1.2 to 2.6 fps and Trichoptera (caddisflies) and Diptera (flies) with velocities of about 3.0 fps. Kimble and Wesche (1975), working on a small stream in southeastern Wyoming, determined that mayflies, caddisflies, and Plecoptera (stoneflies) exhibit preferences for mean water velocities greater than 0.50 fps. Based on limited studies in California, Hooper (1973) considered velocities of 1.5-3.5 fps as optimum for food production. Delisle and Eliason (1961) designated food-producing areas as those where current velocities near the bottom ranged from 0.5 to 3.0 fps. Giger (1973) felt that 0.5 fps is too marginal for food production and defines an ideal range of 1.0-2.0 fps. Regardless of the specific range of velocities, each of these studies points to the fact that food production is greater in riffles than in pools.

Substrate

Substrate size is directly related to water velocity, with larger materials (rubble, boulder) associated with faster currents, and smaller materials (silt, sand) associated with slower currents. The size of the material has been related by numerous investigators to the standing crops of benthic invertebrates. According to Pennak and Van Gerpen (1947) benthic invertebrates decrease in number in the series rubble-bedrock-gravel-sand. Kimble and Wesche (1975) reported a similar decrease in the series rubble-coarse gravel-sand and fine-gravel silt. Sprules (1947) noted that insect emergence decreased over substrates composed of rubble-gravel-muck-sand. Sprules (1947) reported that in general, the diversity of available cover for bottom fauna appears to decrease as the size of inert substrate particles decreases. The majority of research conducted on substrate types have singled out rubble as the most productive. This larger substrate provides the insects with a firm surface to cling to and also provides some protection from the force of the current. These concepts of protection and attachment have been investigated by Ambuhl (1959), Sprules (1947), and Egglishaw (1964).

Depth

According to Kamler and Riedel (1960), water depth influences which habitat benthic organisms prefer. However, the exact influence of depth on food production remains largely unknown. Needham (1934) states that depth influences the photosynthetic production of invertebrate food by regulating the light intensity. The deeper the water, the less the light penetration, the less the photosynthetic production of food, resulting in a decrease in invertebrate numbers. In their study of Prosser Creek in California, Needham and Usinger (1956) found the majority of organisms in relatively shallow, flat areas, with mayflies and caddisflies in depths of less than one foot. Kennedy (1967) reported the greatest numbers of organisms in depths of 3.0-6.0 inches, with decreasing numbers at greater depths. The study by Kimble and Wesche (1975) indicated depth preferences of less than 1.0 foot for mayflies, stoneflies and caddisflies. In general, areas of highest productivity usually occur in trout streams

at depths between 0.5 and 3.0 feet, provided substrates and velocities are suitable (Hooper, 1973).

Other factors thought to influence food production include stream size, light intensity and stream gradient. However, the governing influence to a stream's invertebrate production is found in the parameters of velocity, substrate size and depth. These parameters combine in the riffle sections of streams to provide optimal conditions for the majority of invertebrate species. Riffles are thus much more productive than pool areas.

Drift

Velocity and aquatic insects are also closely related in another way, that being in the delivery of food to the fish by the mechanism called "drift," the movement of the organism downstream by the current. There has been much speculation as to the reasons for drift, some individuals feeling that it is a passive phenomenon while others feel it is an active, voluntary process.

Many investigators (Chapmen, 1966; Elliot, 1967; Mundie, 1969; Waters, 1969; Everest and Chapmen, 1972; Good, 1974) have shown a positive correlation between water velocity and the quantity of drift. Good (1974), in his studies of runoff on Nash Fork Creek in Wyoming, reported that drift rates increased with discharge through June 22-24, whereafter they then decreased to lower levels. According to Waters (1969), water velocity is the major factor influencing the amount of drift, with increasing velocities increasing the drift up to the point of catastrophic conditions.

Other studies have shown increased drift at night (Chapman, 1966; Elliott, 1967; chapman and Bjornn, 1969; Dill, 1969; Everest and Chapman, 1972; Good, 1974). This is largely explained by the fact that most benthic invertebrates are negatively phototactic, hiding during the daylight and becoming more active during the night. The invertebrates are thus more likely to enter the drift during this period of greater activity, for it is at this time that they become exposed to the current.

Reimers (1957) and Dimond (1967) both found evidence that drift was density related. Dimond (1967) found a definite relationship between the number of organisms in the drift and the increased bottom standing crop. This indicated that as the bottom became more crowded, the rate of drift increased. Bovee (1974) offers several interactions which may be involved in this phenomenon: (1) competition for food in dense populations could lead to more searching behavior by the animals, which make them more susceptible to dislodgement; (2) territorial behavior might be practiced and individuals without territories comprise the drift; (3) high population densities might cause animals to spread into marginal habitats which are prematurely vacated. This last interaction suggests that invertebrates may voluntarily enter the drift to remove themselves from a crowded area. Elliott (1967) and Waters (1969) reported increased drift by certain species of mayfly during very low levels of water velocity. It is thought that this apparent voluntary entrance into the drift is done by the organism to create currents for respiration and is associated with drought conditions. Waters (1969) suggests that this type of drift may also redistribute the organisms to sites of more rapid current.

Regardless of whether the phenomenon of drift is voluntary or catastrophic in nature, the supply of drift available to salmonids has been found to be greater in areas of faster current velocity. Thus, if more food is available, it can be theorized that a fish will require less time and space to obtain his food, his territory size can be reduced, and population densities in a given area can be increased.

## Spawning-Egg Incubation Areas

Spawning

A general knowledge of the spawning behavior of salmonids will help to understand their spawning and egg incubation requirements.

As the spawning season approaches, fish residing in the ocean (Pacific salmon, steelhead) or in lakes begin to migrate up rivers and streams in search of suitable spawning areas while resident stream fish will either migrate further upstream or will select areas in their general vicinity. These spawning runs are thought to be initiated by one or more of the following: (1) a sudden decrease in water temperature (Neave and Carl, 1940; Stuart, 1953; Hoppe and Finnell, 1970); (2) a sudden increase in flow due to freshets or spates (Stuart, 1953; Hartman, 1969); (3) a change in water quality (Stuart, 1953); (4) a change in photoperiodicity (Brynildson, Hacker, and Klick, 1973); or (5) some other unknown factor. Lake residents may also utilize the shallow, gravelly areas within lakes for spawning. The spawning area is selected by the female who actively begins construction of the egg nest (redd). As she

turns on her side and rapidly flexes her caudal fin, the substrate is loosened and subsequently carried downstream by the water current. Continuation of this process results in a depression (pit) in the substrate and a mound (tailspill) just downstream, formed by the deposition of the excavated material. Upon completion of the redd, the female facing upstream descends into the pit and is joined by the dominant male. The actual spawning lasts but a few seconds with eggs and milt deposited simultaneously. Immediately the female will swim just upstream of the pit and again begin the cutting and digging activity previously described. This effectively covers the eggs just deposited and constructs an additional nest in which to spawn. Although freshwater salmonids desert the nest after spawning, the Pacific salmon generally will remain at the spawning site until they die, usually in about two weeks.

Spawning habitat has been defined by numerous individuals (Thompson, 1972; Hooper, 1973; Hunter, 1973; Smith, 1973; Sams and Pearson, 1963; Reiser and Wesche, 1977) who have measured the hydraulic and physical parameters existing in the stream sections utilized by actively spawning fish. Parameters considered include water velocity, water depth and substrate size. Generally, acceptable spawning areas exhibit water velocities between 0.50-3.0 fps, water depths of 0.50 feet or greater and substrate sizes between 0.25 and 3.00 inches. To a large degree, fish size will determine if an area is acceptable for spawning, with larger fish being able to dislodge larger substrate and endure swifter currents than smaller fish. According to Hunter (1973), interspecies spawning preferences for salmonids of the same size will be closer than intraspecies requirements for fish of varying size.

Incubation

The successful development of the incubating eggs is dependent upon certain chemical, hydraulic and physical parameters.

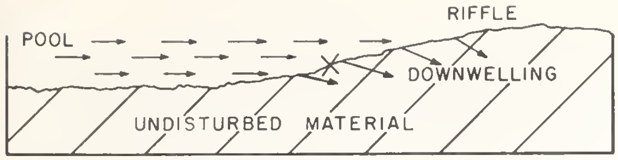
Chemical. The most important chemical parameter relative to incubation is dissolved oxygen. The development of salmonid eggs is directly related to dissolved oxygen, with ever-increasing demands for it as the eggs develop, and a maximum requirement just prior to hatching (Hayes, Wilmot and Livingstone, 1951; McNeil, 1964). Recommended incubation flows for the Snake River in Hells Canyon were based on having at least 5.0 mg/l intragravel dissolved oxygen for the spawning salmonids (Thompson, 1974). Hatchery operations are best carried out in water having a dissolved oxygen concentration of 7.0 mg/l (Bardach, Ryther and McLarney, 1972) (see section on Water Quality).

Hydraulic. Hydraulic parameters important in comprising a good incubation environment include the percolation rate of water through the spawning gravels, a pool-riffle sequence, and to a degree, groundwater seepage.

Because the percolation of water brings the necessary oxygen to the incubating eggs, and removes the metabolic waste materials, the percolation rate influences the length of the incubation period and the relative sizes of new fry (Shumway, Warren and Doudoroff, 1964). This of course is dependent on the dissolved oxygen concentration. In two redds with different percolation rates but with the same concentration of dissolved oxygen, conditions for embryonic development may be better in the area with the higher exchange rate of water (Coble, 1961).

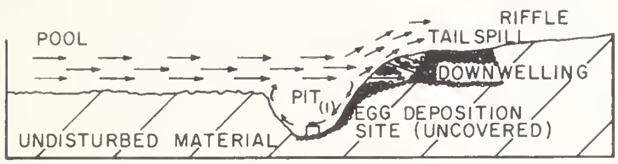
A pool-riffle sequence in streams is important in providing cover, resting, and food-producing areas. The interchange area between a pool and riffle provides an excellent spawning environment, with velocities great enough to carry away silt and debris which may clog the redd substrate. In addition, the stream bottom at the lower end of a pool gradually assumes a convex appearance as the riffle area approaches, causing a downwelling of the current into the substrate. The convex nature of the tailspill also causes downwelling of water into the egg nest. Figure B-1 shows the nature of currents, including downwelling, before, during and after spawning. Vaux (1962) has shown that both increased permeability and a convex streambed induce downwelling while a concave streambed causes upwelling. This movement of water into the gravel provides a constant supply of oxygen to the eggs and effectively removes metabolic waste materials. In addition, Stuart (1953) has suggested that this downward current may assist the female on the spawning grounds in maintaining her position against the force of the current.

Numerous investigators (Kendall, 1929; White, 1930; Greeley, 1932; Hazzard, 1932; Webster and Eiriksdotter, 1976; and others) have shown that brown (*Salmo trutta*) and particularly brook trout (*Salvelinus fontinalis*) select spawning sites in areas with groundwater seepage. This may also be true of other salmonids. Benson (1953) found a direct relationship between the amount of groundwater, size of trout populations and number of redds.



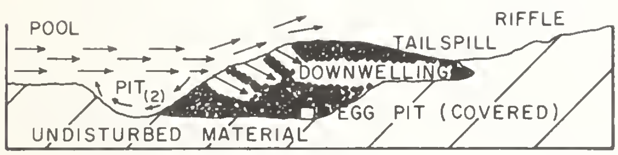

Before Spawning

Convex nature of substrate at pool-riffle interchange induces downwelling of water into the gravel. (X) marks an area likely to be used for spawning.




During Spawning

Redd construction results in negligible currents in the pit (facilitating egg deposition) and increased currents over and through (downwelling) the tailspill.




After Spawning

Egg covering activity results in the formation of pit (2) (may also be used for spawning) and the covering of the eggs in pit (1). Increased permeability and the convex nature of the tailspill substrate induces downwelling of water into the gravel creating a current past the egg deposition site. The water current brings oxygen to the eggs and removes metabolic wastes.

Figure B-1. Longitudinal sections of spawning areas showing nature of currents before (top), during (middle), and after (bottom) spawning. (Modified from Hobbs, 1937.)

It was thought that the groundwater would provide a constant flow over the eggs ensuring sufficient dissolved oxygen for development. Also, as groundwater temperatures are often warmer than surface waters in the winter, the eggs are protected from freezing conditions and hatching time is reduced. Latta (1967) feels that in years of high groundwater levels there is a greater survival of eggs and fry than in years with low levels. Hansen (1975) has shown that brown trout spawn in areas with and without groundwater inflow in about equal numbers. Where groundwater inflow was present, the brown trout preferred areas of intermediate surface-groundwater mix and avoided areas where strictly groundwater flowed. The warmer groundwater is able to hold less dissolved oxygen than the surface water and at the same time may cause an increased demand for oxygen by the developing embryo. Hansen (1975) suggests that the major benefit of groundwater may be the wide range of hatching dates which ensures the survival and recruitment of new fish.

Physical. Primary physical parameters important in incubation include water temperature and permeability of the substrate.

To a large degree, the rate of egg development is dependent upon water temperatures, with the higher the temperature (to a point), the faster the egg development. For example, brown trout eggs will take 156 days to hatch at a temperature of 35°F (1.6°C) but only 41 days at 50°F (10°C) (Leitritz, 1969).

The permeability of the substrate surrounding the eggs determines to an extent the percolation rate of water through the redd. This is important in two respects: (1) dissolved oxygen is brought to the developing eggs via the percolating water; and (2) metabolic wastes are removed from the developing eggs via the percolating water. According to McNeil and Ahnell (1964) the permeability of the material is dependent on: (a) density and viscosity of water; (b) porosity of streambed; and (c) size, shape, and arrangement of solids. Permeability is considered high by McNeil and Ahnell (1964) when the bottom materials contain less than 5 percent by volume of sands and silts passing through a 0.033 inch (0.833 mm) sieve, and is low when the materials contain greater than 15 percent. The nest construction activity of the female, in effect, cleans the substrate of the very fine materials and results in gravel with a high permeability. However, certain land use practices such as timbering, road construction, and overgrazing can result in increased sediment loads being deposited in the interstices of the spawning gravels, reducing the permeability of the substrate and percolation of water to the developing eggs. This of course may result in an increase in egg mortality.

Thus, successful reproduction of salmonids depends on the presence in a stream of sufficient areas suitable for spawning which possess environments conducive to egg incubation.

## Cover

Cover can be defined as those instream areas providing the fish protection from the effects of high current velocities and predation. Cover for fish in streams can be provided by overhanging vegetation, undercut banks, submerged vegetation, submerged objects (stumps,

logs, roots, rocks), floating debris, and water turbulence (Giger, 1973). The extent to which each of these forms is used is dependent upon species preference, and of course upon its availability in the stream. As was noted by Giger (1973), the cover requirements of mixed populations of salmonids are not easily determined. Shelter needs may vary diurnally (Kalleberg, 1958; Allen, 1969; Chapman and Bjornn, 1969), by fish species (Hartman, 1965; Ruggles, 1966; Allen, 1969; Chapman and Bjornn, 1969; Lewis, 1969; Pearson, Conover and Sams, 1970; Wesche, 1973) and by fish size (Butler and Hawthorne, 1968; Allen, 1969; Chapman and Bjornn, 1969; Wesche, 1973).

Overhead cover may consist of overhanging vegetation (trees, grasses, etc.), logs, or undercut banks. Many investigators (Newman, 1956; Wickham, 1967; Butler and Hawthorne, 1968; Baldes and Vincent, 1969; Chapman and Bjornn, 1969; Lewis, 1969) have shown that overhead cover is used by many species of salmonids, brown trout, brook trout, and rainbow trout (Salmo gairdneri) which exhibit photonegative behavior. Overhead cover is also utilized by species showing thigmotaxis (desire to be in close contact with an object). Giger (1973) cites another use of overhead cover, that being in providing shadow areas along stream margins where water currents are, for small fish, frequently optimal for resting.

Butler and Hawthorne (1968) and Lewis (1969) report that brown trout utilize overhead cover to a greater degree than rainbow trout. Wesche (1973) determined that brown trout utilize overhead bank cover more so than instream rubble-boulder areas and devised a cover rating system whereby cover comparisons can be made on a stream section at different flows or on different stream sections at the same flow. Wesche (1974) began subsequent investigations into the relationship of cover to standing crop.

Submerged cover (e.g., stream substrate, aquatic vegetation, etc.) has been shown to be important in all stages of salmonids, from the newly hatched swim-up to the adult. Even salmonid eggs rely on submerged cover (substrate) for protection. Hoar, Keenleyside and Goodall (1957) and Hartman (1965) reported that small salmonids recently emerged from the spawning gravel frequently hid under stones. Wesche (1973) noted that brown trout less than 6.0 inches used instream rubble boulder areas to a greater degree than overhead cover. This suggests, as was noted earlier, that cover selection is in part based on fish size.

Generally, fish will establish a territory around the selected cover type. This tends to spread the fish population throughout the stream system, leading to a more efficient utilization of the food supply (Hunter, 1973). It is within this microhabitat that the fish will spend the majority of his time, feeding and resting. According to Hunter (1973) a fish which has succeeded in obtaining a station with favorable feeding conditions usually retains the territory partly by aggressive actions and partly because he grows faster than his neighbors who have less desirable stations. Hooper (1973) states that abundance of suitable cover determines the number of territories, and thus, the fish population.

That cover is indeed important is shown by the effects of its removal from different streams. Elser (1968) found 78 percent more trout in an unaltered stream section than in an altered section having 80 percent less cover. Boussu (1954) showed that losses in brush and undercuts from a stream section resulted in subsequent losses in the number and weight of resident trout. Peters and Alvord (1964) noted similar reductions in twelve Montana streams.

Stream improvement projects whereby the amount of cover is increased also show the importance of cover. Studies conducted by Tarzwell (1937, 1938), Shetter, Clark, and Hazzard (1946), Warner and Porter (1960), Saunders and Smith (1962), and Hunt (1969, 1976) have shown that stream improvement, by increasing the amount of habitat, increases the size and numbers of fish. Cooper and Wesche (1976) conducted a stream channel modification study in an attempt to maximize available trout habitat in streams having extended periods of low flow insufficient to sustain a fishable trout population. Preliminary evaluations of their work indicate favorable results.

## Summary

From the above discussion of water quality, food-producing areas, spawning-incubation areas, and cover, it becomes apparent that all are necessary components for the maintenance of a viable salmonid population. The elimination or reduction of one or more of these elements will have a marked effect on the fishery and rehabilitative measures must be undertaken.



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